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CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

NINTH

ANNUAL REPORT

OF THE

GEOLOGICAL COMMISSION.

1904.

Presented to both Houses of Parliament by command of His Excellency the Governor.

1905.

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NINTH

Annual Report of the Geological Commission,

1904.

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Geological Commission of the Colony of the Cape of Good Hope
1904

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Superintendent-General of Education.

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ARTHUR WILLIAM ROGERS, M.A., F.G.S.

Geologists—
ERNEST H. L. SCHWARZ, A.R.C.S., F.G.S.
ALEX. L. DU TOIT, B.A., F.G.S.

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Cape Town,
10th January, 1905.

The Hon.
The Secretary for Agriculture.

SIR,—I have the honour to forward herewith the Annual Report of the work of the Commission for the year 1904.

Owing to the general financial depression, the Commission have felt it their duty to modify their programme in order not to exceed the vote taken, keeping in mind, however, the necessity for a continuous and connected advance towards the general geological survey of the Colony.

As will be seen from the Report of the Director, satisfactory progress continues to be made and results of great scientific interest have been obtained.

Recent events in adjoining Colonies have shown what an intimate bearing these scientific data may have, in certain contingencies, upon the economic development of the great mining industry in South Africa.

It is to be hoped that the financial position of the Colony may before long warrant the resumption of the work of the Commission in certain directions which has been for the time suspended.

I have the honour to be,
Sir,
Your obedient Servant,

JOHN X. MERRIMAN,
Chairman.

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GEOLOGICAL SURVEY

OF THE

COLONY OF THE CAPE OF GOOD HOPE.

REPORT OF THE DIRECTOR FOR THE YEAR 1904.

The amount of field-work which forms the basis of this Report is considerably less than it would have been had sufficient money been available for the purpose of making the greatest possible use of the services of the staff.

From the end of April till August I worked in Van Rhyn's Dorp, when the survey of the Division was nearly completed. A small area in the extreme north was left out owing to the expense that would have been incurred in reaching it by means of hired transport at a time when the inland farms were temporarily deserted on account of the drought. The results of this work are printed here, and a sketch map illustrating it and the neighbouring country to the east and south is added. Among the points of interest raised may be mentioned the finding of a new and possibly important group of Pre-Cape sedimentary rocks here, called the Nieuwerust beds. Whether this group belongs to one that has been previously described from the country further north is uncertain.

In Van Rhyn's Dorp the southern end of the great group of igneous rocks, chiefly granite, that occupy an enormous area in the north-west of the Colony, is met with. The observations in this district show that these rocks were intruded into the slates and limestones here classed with the Malmesbury beds. There is no proof that these sedimentary rocks belong to the group to which the name Malmesbury series is applied in the south-west, between the Cape Peninsula and Verloren

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Vley, but lithologically they are similar, although there is more limestone in the Van Rhyn's Dorp area; it should be remembered that limestones exist in the so called Malmesbury beds of Piquetberg, Vogel Vley, and of the elongated area north of the Worcester fault. In the absence of fossils, the correlation of these isolated beds is of course doubtful, but it is convenient to use one name for them. The survey of the whole granite and schist area of the north-west is likely to yield facts of much importance from an economic point of view and of very considerable scientific interest, but it will take several years to complete on account of the difficulties of travelling in such a dry region.

There are several difficulties left partly solved in the geology of Van Rhyn's Dorp; some of these require a larger scale map for their elucidation, and others are due to the impracticability of revisiting localities from which rocks of uncertain character came, so that when these rocks had been examined in a detailed way the full use of the information could not be made.

Mr. Schwarz took a month's leave after completing his office work for the 1903 Report, and then did six weeks' field work in the Long Kloof. This area lies south of the country mapped by him during the previous year. There is another outlier of the Uitenhage series (Enon type) in this area. The earth-movements which so strongly affected that part of the Colony have had an even more pronounced effect in the Long Kloof than to the north. Two maps accompany this Report.

Mr. du Toit was occupied for five months in the north-east of the Colony, and the account of his work together with the map, which includes the area surveyed by him on the southern side of the Drakensberg last year, contains a great addition to our knowledge of both the sedimentary and volcanic beds of the Stormberg series.

It is disappointing to notice that while the sedimentary rocks as a whole, including the coal beds, become more regular to the north, in Aliwal North and Herschel, than they are in the southern part of the area occupied by the Stormberg series, yet the discovered seams of coal are thinner and of much less value than in the

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south. There are fewer intrusions of dolerite in the northern area, so that, should a good coal be found there, it is likely to be more constant and less liable to be damaged by dolerite than is the case in the Stormberg coal area hitherto worked. The northern area has not been prospected to the same extent as the southern, and it is possible that valuable seams remain to be found, but the hope that this should be the case does not derive support from the existing evidence.

Considerable additions to the known fauna of the upper part of the Beaufort series and the Stormberg series have been made. It has been found convenient to give the uppermost part of the Beaufort series the name of Burghersdorp beds. In the Red beds and Cave sandstone several fossils have been found, and great interest attaches to the crocodile *Notochampsa*, a new genus related to crocodiles from the Jurassic formation of other countries. The discovery of Phyllopoda and insect wings in thin shale beds in the Cave sandstone is also of great interest. In the account of the Volcanic beds of the Stormberg series there will be found much that is new. The volcanic pipes have been found to be distributed over a great extent of country, and they are not confined to particular lines. The view that there is an intimate connection between the uppermost sedimentary deposits of the Stormberg series and the volcanic rocks receives strong support from the results of this work.

A commencement has been made in the re-arrangement of the collections obtained by the geologists. The Uitenhage and Karroo plants have been separated from the general collection and classified, and sets of named duplicates have been distributed to other South African institutions. The same course will be pursued in the case of the Bokkeveld invertebrates and other groups of fossils as opportunity offers. The rocks will probably be treated in the same way, as the specimens are more convenient for reference when classified, then when merely put away in the order in which they happen to be found.

The accompanying diagram shows at a glance the area surveyed since the commencement of the work in

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1896. It was intended to continue the mapping of the south-western districts until about a quarter of the Colony had been completed, and then to issue a coloured map on the same scale as that of the work done previous to June, 1898, and published with the Report for 1897. Several circumstances have interfered with the carrying out of this plan, and experience has shown that the larger scale maps, done in black and white, published in several Reports are more useful than the small scale coloured map, though the use of black ink only, involves the omission of details such as farm beacons, which is a serious loss in many cases. It is to be hoped that maps of a large part of the country on a scale of not more than 4 miles to the inch, printed in colour, will one day be available to the public by purchase ; the scale suggested will allow most of the farm boundaries to be put in without overcrowding the map. The material for such maps of the areas covered with lines or stippling on the diagram is available, and can be consulted in the office of the survey, but it is naturally difficult of access to most people.

Though the work of mapping is being carried on as rapidly as the available funds allow, and as rapidly as is consistent with the insertion of as much detail as the topographical maps will bear, the whole of the Colony will not be covered under thirty years unless the staff be increased ; in the meanwhile more detailed mapping of areas that are of particular importance must be left in abeyance, though it is very desirable that a rather large scale map of certain districts, the Cango for instance, should be made.

Since the end of last year four parts of the Palæontological Volume of the Annals of the South African Museum have been issued ; one of these, by Mr. P. Lake, deals with the trilobites from the Bokkeveld beds, and in it eight new species are determined, and three which are not well enough represented in our collection for exact determination are mentioned ; five of the previously known species are described and re-figured. Mr. F. R. Cowper Reed's paper on the Brachiopods of the Bokkeveld contains descriptions and figures of five new species and of eleven others that were previously

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known from America or the Falkland Islands but not from South Africa; the same author's paper on the Bokkeveld Mollusca deals with eight new species and twenty-five forms new to South Africa in addition to the previously known species. In Mr. F. Chapman's account of the Foraminifera and Ostracoda from the Pondoland Cretaceous beds twenty-four species and varieties are determined, all of which are new to the Colony and five of which are new to science. Owing to want of money the palæontological work has mostly been stopped, only that part of it being continued which was nearly completed early in the year. The papers that have been published are of very great value to the survey and have created a wide interest abroad; within the Colony there have been some enquiries for the descriptions, but not to the extent one would wish. The necessarily technical descriptions given in the Annals is a bar to their general use, but to a great extent the illustrations remove the difficulty of identifying the fossils.

The Index to the first eight Annual Reports, from 1896—1903, is in the press.

The following papers by the members of the staff have appeared in the Transactions of the South African Philosophical Society during the period covered by this Report:—

"The Sutherland Volcanic Pipes and their relationship to other vents in South Africa," by A. W. Rogers and A. L. du Toit.

"High-level Gravels of the Cape and the Problem of the Karroo Gold," by E. H. L. Schwarz.

We have again to thank Mr. J. Lewis of the Government Analytical Laboratory for several determinations of silica percentages and other similar investigations, and Prof. Broom, of Stellenbosch, for much information regarding reptilian fossils.

ARTHUR W. ROGERS.

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System	Series	Beds			Correlation	Period
Recent or Superficial Deposits.					Post Tertiary ?	
Cretaceous system	Cretaceous series of Pondoland	Umzamba beds			........Senonian	Cretaceous.
		Embotyi beds				
	.... ?					
	Uitenhage series	Sunday's River beds			........Neocomian	
		Wood beds				
		Enon beds				
	....					
Karroo system	Stormberg series	Volcanic beds				Jurassic ?
		Cave sandstone				
		Red beds				
		Molteno beds........			Rhaetic	Triassic.
	Beaufort series	Burghersdorp beds	Kentani beds			
		Dicynodon beds			........Permian	Permian.
		Pareiasaurus beds	Idutywa beds			
	Ecca series	Upper shales	Umsikaba beds	Graaff-Reinet beds		Carboniforous.
		Laingsburg beds				
		Lower shales				
	Dwyka series	Upper shales				
		Conglomerate				
		Lower shales				
	.... North of lat. 30°					
Cape system	Witteberg series					
	Bokkeveld series........				Lower ? Devonian	Devonian.
	Table Mountain series				Silurian.	
	....					

	In North.	In West.	In South.	
Pre-Cape Rocks	Matsap series	Nieuwerust series	Cango series	Archaean.
	....	....	.... ?	
	Griqua Town series	Ibiquas series	Malmesbury series	
	Campbell Rand series	....		
	.... ?	Malmesbury series		
	'Keis series			

This Table gives the classification of the formations in Cape Colony used at present by the Survey.

The positions of the divisional lines between the Burghersdorp and Dicynodon beds and between the Dicynodon and Pareiasaurus beds are still uncertain, though there is no doubt as to the order of succession. The correlation of the Pre-Cape rocks in the north, west, and south of the Colony is unknown.

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GEOLOGICAL SURVEY

OF THE

NORTH-WESTERN PART OF VAN RHYN'S DORP.

BY

A. W. ROGERS.

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GEOLOGICAL SURVEY

OF THE

NORTH-WESTERN PART OF VAN RHYN'S DORP.

BY A. W. ROGERS.

INTRODUCTION.

The area described in the following pages comprises about 1,700 square miles of country, situated north of the Olifant's River and west of the Bokkeveld escarpment; on the north, it is bounded by a line passing through Bitter Fontein and Louis Fontein, in the Harde Veld, and reaching the sea at the Salt River* mouth.

The great escarpment forming the eastern limit of the district is the most conspicuous feature in it. The rest of the area is relieved by a few hills of considerable height, and none of them rise to the rank of mountains, though in the Harde Veld, the Karree Berg, Flamink Berg, and the neighbouring hills are the remnants of a formerly high range. Immediately west of the Bokkeveld escarpment there is a wide tract of flat and gently undulating ground, the northern portion of which is called the Knegt's Vlakte, a dry, barren country, some 1,200 square miles in extent. Only the western and southern edge of the Knegt's Vlakte comes into the area dealt with here; the geology of the eastern portion of the Vlakte is described in a former Report.† The greater part of this flat country is only used during the winter months, and then only for grazing; but the southern end, which receives more rain, is permanently inhabited, and parts are under cultivation. To the west of the Flats there lies a great tract of sandy country, the northern continuation of the Sand Veld of Piquetberg and Clanwilliam; but the Harde Veld forms a broad wedge, directed southwards, extending to within 5 miles of the Olifant's River, and separating the Knegt's Vlakte from the Sand Veld of the coast.

* Usually known as Zout Rivier, but here called Salt River to distinguish it from the other Zout Rivier, crossed by the main road between Van Rhyn's Dorp and Nieuwerust.

† Ann. Rep. Geol. Com. for 1900, pp. 25 etc.

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The chief river in the district is the Olifant's, which drains the country far to the south and west, and only receives occasional additions from the northern part of Van Rhyn's Dorp, through the usually dry channels of the Hol, Drooge Kloof, and Varsche Rivers, draining the Knegt's Vlakte and the flat country south of it. The Harde Veld is chiefly drained by small streams running directly to the coast, but the Groot Graafwater and Moed Verloren Rivers, tributaries of the Hol River, receive some of the water from its southern part. It is by no means during every year that water runs in these river beds; during the present survey of the district several of them were without even the temporary pools which are left after the river ceases to run, and which last for considerable periods.

In the granitic region of the Harde Veld there are large pot-holes, many feet in diameter, and as much as 15 feet in depth, in some of the steeper portions of the river channels, and these are the chief sources of water during the dry season; good examples are to be seen at Groot Goerap, in the bed of the river of the same name. Many farmers are still dependent for their water on the irregularly-shaped hollows on the surface of the massive granite, which are filled by occasional showers. In some cases, as at Kom Kas, these water holes, many feet above the present river bed, have the appearance of old pot-holes long forsaken by the river. The holes are filled with gravel and sand, until they are discovered and cleared of their contents by the farmers. In many other cases the water-holes are elongated in the direction of the principal jointing, or it may be the foliation planes of the rock, and are obviously due to the unequal progress of weathering in different directions on a large surface. This class of water-hole is much shallower than the other; but from the care taken to enclose the vicinity of the holes with walls or wire, it is evident that they are valued highly. Occasionally they have been enlarged by blasting. The water in all these holes is derived directly from the rain; in no case that came under observation does the supply come from a spring.

Springs are extremely rare in this area, and the water from them is brak, as is also the case with the wells. Further remarks on the underground water supply will be made after the geology of the area has been described.

The sedimentary rocks in this district are of Pre-Cape age, with the exception of small areas of Table Mountain sandstone and the recent deposits; and we have to deal with the extreme southern end of the huge body of granite and gneiss that, according to Wyley, Dunn, and other geologists, occupies a great part of the Namaqualand Division.

THE MALMESBURY SERIES.

The oldest rocks probably belong to the Malmesbury series, and they are continuous with the beds of that group described

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in the Report dealing with the country south of the Olifant's River.* They occupy the country north of that river as far as a line drawn from Schaap Vley, near the coast, to the Moed Verloren River at Klip Drift Extension; thence they extend northwards to the Groot Graafwater hills; from the eastern portion of the farm Groot Graafwater the boundary runs south-eastwards to the Kobe Mountains, which it meets at Klip Fontein. On the coast the Malmesbury beds stretch a few miles north of Schaap Vley, and they occur again on North Hartebeest Kom. Over the greater part of the area thus defined the rocks are concealed by thick recent deposits, and it is usually only along the few river courses that exposures can be found. An inlier of small extent, but of great interest, occurs in the valley of the Kobe River, or Oorlog's Kloof River, behind the Kobe Mountains, the southern continuation of the Bokkeveld escarpment.

The Malmesbury beds in this district consist of slates, black slates, phyllites, quartz schists, and crystalline limestones or marbles. Their general strike is about north-north-west, and the dips are usually very high. The group has been folded at two distinct periods, and has been invaded by the Namaqualand granite. It is impossible, without a much more minute survey than can now be made, to ascertain the structure of the area in detail, but the observations made during the present survey, combined with previously known facts, enable one to arrive at some conclusions on the subject.

The normal order of succession, from above downwards, appears to be as follows:

Slates and phyllites, with thick bands of schistose quartzites and thin bands of felspathic grits, top not seen	3,500 feet.
Crystalline limestones of Aties, etc., with interbedded black shales and slates, and limonite beds, at least	1,000 feet.
Black slates and phyllites, bottom not seen.	

The various thicknesses assigned to these beds are quite uncertain. In the case of the Aties group, the beds occupy a wide belt of country, measuring at least 16 miles across the strike between their limit north-east of Van Rhyn's Dorp and the Olifant's River, above Vredendal, but the rocks are hidden over considerable stretches, and where they can be seen, the arches and troughs of folds are frequently exposed, often with both limbs inclined in the same direction, so that the great width of the belt of similar rocks is certainly due to the repeated folding of a very much thinner group of strata. Within short distances, as, for instance, in the section below Aties on the Troe Troe River, the beds can be identified at their different outcrops; but

* Ann. Rep. Geol. Com. for 1903, pp. 143—149.

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the attempt to correlate particular bands of limestone or black slate in the Troe Troe section with similar bands in the Zout and Groot Graafwater Rivers failed.

Generally speaking, the dip of the beds belonging to the Malmesbury series is to the westward, though there are many exceptions near the village of Van Rhyn's Dorp and on the coast. The Malmesbury beds in the neighbourhood of Vredendal and along the Olifant's River, between Vredendal and Olifant's Drift, appear to be less disturbed than elsewhere in the district, and it is from that area that the succession as given above was taken.

Along the north-eastern boundary, where they are in contact with the Ibiquas beds, an overthrust fault probably separates the two formations, though it is, perhaps, more likely that part of the boundary is an overfolded unconformity. The conglomerates and coarse grits of the Ibiquas contain numerous fragments of crystalline limestones, phyllites, granites and gneiss, just like the sedimentary rocks of the Malmesbury series and the igneous rocks that invade them, and they were very probably derived from those sources. In the absence of fossils, it is impossible to prove the derivation, but the resemblance is so close that we are justified in regarding them as very strong evidence of an unconformity between the Ibiquas and Malmesbury series, and also as indicating that the granitic intrusions in the latter group were exposed to denudation when the Ibiquas beds were being deposited. The conglomerate beds occur in a greatly-disturbed belt between Klip Fontein, under the Kobe escarpment, and the upper part of the Groot Graafwater valley; the slates accompanying them are not easily distinguished from the slates of the Malmesbury series, and the whole western portion of the Ibiquas group dips at high angles westwards, *i.e.*, under the Malmesbury beds, though when followed eastwards the disturbances become less and less pronounced, until in the wide valley behind the Stink Fontein Poort the Ibiquas beds lie in gentle folds, and are not more altered from their original condition than are the Bokkeveld beds on the flank of the Cederbergen.*

The explanation of these facts is that the area was subjected to great pressure from the west after the deposition of the Ibiquas beds, when the Malmesbury series was thrust over the Ibiquas, and at the same time the former received a new-folded structure, which was superimposed on the earlier changes wrought by the intrusion of the Namaqualand granite and the earth movements that preceded or accompanied it. A close survey of the boundary with the aid of a much larger scale map will be necessary for the satisfactory explanation of its structure.

* For a fuller description of the eastern part of the Ibiquas beds, see Ann Rep. Geol. Com. for 1900, pp. 25—30.

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From the junction with the Ibiquas beds on the northern part of Groot Graafwater westwards to Pot Kley, the Malmesbury beds are overlain unconformably by the Nieuwerust series, and thence southwards they are in contact with the granitic rocks. This junction seems to be a faulted one, with downthrow to the east, as far as the south-western corner of the farm Mostert's Kop, a distance of over $4\frac{1}{2}$ miles; but from there southwards to Klip Drift Extension, on the Moed Verloren River, the contact is probably due directly to the intrusion of the granite, as it certainly is at Klip Drift Extension and along the southern slopes of the Drooge Kraal hills (southern part of the area called Moedverloren Hills on the map). From this neighbourhood to the coast, the junction is entirely hidden under the deep sand of the Sand Veld.

The black slates and phyllites below the Aties group crop out in some of the anticlinal folds along the Widouw and Troe Troe Rivers, and again on the farm Roode Berg, north of Zout River. They are intensely crumpled, more so than the thick limestones above. Many outcrops show but slight development of sericite, which is a usual and abundant constituent of the beds above the Aties group. The rocks are often deeply weathered into variously-coloured, clayey material. Some beds are black, owing to the amount of carbonaceous matter they contain, and they weather into black and finally white clays, like those to be described from the Aties beds.

The Aties group is the most interesting of the three sets of beds into which the Malmesbury series in this district is here divided. The characteristic feature in it is the abundance of crystalline limestone. The prevailing tints of the limestone are blue or grey, but many beds are dark grey or even black, owing to the quantity of organic matter present in them. The darker rocks give out a strong smell when broken, just as the dark beds in the carboniferous limestone of England do when crushed. Both the dark and light coloured beds were searched for fossils, without results. The residue, after treatment with weak acid, consists of flocculent, black carbonaceous matter and quartz grains. These bluish beds are mostly composed of carbonate of lime, for this rock is easily dissolved by dilute hydrochloric acid, but magnesium carbonate is present in some of them. A typical pale-blue crystalline limestone from Aties, examined by Mr. J. Lewis, of the Government Analytical Laboratory, contained only a trace of magnesium carbonate. The blue limestones occur in the Troe Troe Valley, between Van Rhyn's Dorp and Vredendal; at Klip Fontein, under the Kobe Mountain; on Keerom and Groot Kobe, behind the escarpment, and along the courses of the Groot Graafwater and Hol Rivers. Below the boundary fence, between Vredendal and Aties, the rock becomes streaked with white layers, from one-tenth of an inch to several inches in thickness, and along both banks of the

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Olifant's River, below the confluence of the Troe Troe, thick beds of finely crystalline, yellowish-white limestone are exposed; below Bruin Klip the white limestone is no more seen, but the blue and white rock appears again at many places between Vleermuis Klip and the great bend of the river at Ko Kenaap or Roode Heuvel. It is impossible at the present time to settle the question of the relationship of these varieties of limestone—that is, to determine whether they are on distinct horizons, or whether the same group of beds is being dealt with throughout. The outcrops along the Olifant's River are separated by wide intervals of alluvium, and as a rule there are no exposures at a distance of more than a few yards from the river banks.

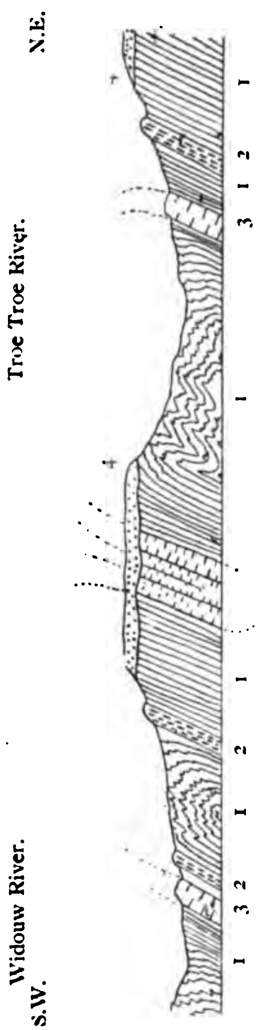

Fig. 1.—Section across the Troe Troe and Widouw Valleys below Aties. Horizontal Scale, 1 in. = 2,000 ft. Vertical Scale, 1 in. = 800 ft. 1 Slates. 2 Limonite (greatly exaggerated in thickness). 3 Limestone. 4 Surface deposits.

Between the beds of limestone there are frequently thin layers of slate, or hard shale, with roughly developed cleavage, and thick masses of similar rock separate groups of limestone beds. These argillaceous beds have crumpled under the influence of the pressure which produced the folds in the district to a much greater extent than the limestones. As indicated in a diagrammatic manner in fig. 1, the lamination planes in the slates are often very greatly distorted, while the massive groups of limestone, sometimes 500 feet across the bedding planes, do not show such disturbances, though in places where the latter rock is thinly laminated by bands of slightly different colour and composition crumpling is sometimes seen.

Certain layers in the Aties group are very soft, at least at the outcrop and within two or three feet of the surface; they are plastic clays, containing a considerable percentage of carbon. A specimen from the farm Aties was found by Mr. J. G. Rose,

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Government Analyst, to contain 46·42% of carbon; the condition of the carbon has not been ascertained, but it is probably almost all in the form of graphite. Under the microscope the clay is seen to consist of extremely small black particles, with a few quartz grains of sufficient size to be identified. The presence of such a soft clay amongst beds that have suffered shearing to a considerable extent is peculiar; but it is possible that the soft character of the rock is due to weathering.

At places the black layers contain pyrites, and then the rock weathers white, owing to the oxidation of the carbonaceous colouring matter.

On the farm Klip Drift Extension, the Aties group is invaded by the granite and gneiss. There are no outcrops in the immediate neighbourhood of the junction, but from two wells, one on either side of the Moed Verloren River, about 300 yards apart, I obtained typical biotite gneiss in the one case, and mica schist and yellow crystalline limestone, with crystals of phlogopite, in the other. The yellow or, rather, cream-coloured marble was found by Mr. Lewis to contain about 40% of magnesium carbonate. There are minute specks of graphite in the marble.

In many places where the limestone occurs there are occasional layers of brown or black limonitic iron ore. These are especially frequent in the neighbourhood of Aties. They appear to be interbedded with the marble, for they have not been found cutting across the bedding planes of the enclosing strata. The rock is generally black on a weathered surface, and has a botryoidal form in the irregular cavities that occur in it. A freshly-broken surface is brown. In places the rock is somewhat siliceous, and very narrow veins of quartz traverse it. Some of the Aties limonitic beds reach a thickness of 20 feet, and can be followed as far as the absence of superficial deposits allows—in one case, a distance of rather over one mile. The beds are lenticular in form, and can often be proved to disappear by decreasing gradually in thickness in one or both directions along the strike. In the case of a syncline cut through by the Troe Troe about a mile below the drift at Aties, outcrops of the ferruginous rock occur in symmetrical positions in each limb of the fold, and some 200 yards apart, as though they were parts of one continuous bed. On the farm Moed Verloren, at a short distance north of the Klip Drift boundary, there is an outcrop of extremely hard, yellowish-brown jasper. It is the nearest outcrop of rock, other than granite, to the well from which the phlogopite-bearing marble came, and it probably lies 1,000 feet from the granite boundary. It may be a limonite band, altered by the influence of the granite, but no minerals characteristic of contact metamorphism were found in it. Near the road from Ko Kenaap to Drooge Kraal, some outcrops of hard limonite

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project above the sand, and these may belong to the Aties group.

On the southern part of the farm Groot Kobe and on the right bank of the Kobe River there is a very interesting exposure of red banded jasper, which dips towards the thick limestone to the west. The jasper beds, of which at least 50 feet are visible, have a great resemblance to parts of the Griqua Town beds, as seen in the Doornbergen, near Prieska. The locality is somewhat difficult of access, unless one is camping in the Kobe Valley, and I was unable to examine it thoroughly. The jasper lies between the limestone and the Ibiquas beds, which are exposed on the opposite bank of the river, and from which it is probably separated by a thrust fault or the axis of an overfold. The basal grits and conglomerates of the upper series crop out on the right bank of the river, about 500 yards above the exposures of the jasper. West of the Kobe Mountain the nearest analogues to the jasper are a thin band of cherty rock under the limestones on Klip Fontein, and the hard ferruginous rock at Moed Verloren and Ko Kenaap, but these are very different in appearance from the Groot Kobe rock. So far as is known at present, Groot Kobe is the only place outside the northern districts where banded jasper rock of the Griqua Town type occur, and as it is in close association with crystalline limestones, that are comparable with the Campbell Rand group, we are justified in hoping that it may be the means of correlating the rocks, so far as that can be done on lithological grounds. The Kobe Valley is worthy of much more attention than we have yet been able to give to it.

The uppermost division of the Malmesbury series in this district consists of slates, phyllites, schistose quartzites, and grits. The rocks are best seen along the Ongegunde Fontein coast, which was described in the last Annual Report.* To the north of the Olifant's River the phyllites are well exposed on the coast as far as Geelwal Karroo; they appear in precipitous cliffs, and are overlain by superficial deposits. They are silky sericitic schists, much veined by quartz, and they are highly contorted, but the strike is fairly constant in a direction about 10° west of north. Inland there are very few outcrops, but along the Olifant's River, below Ko Kenaap, rather gritty sericitic slates occur at several points, and at Priems Bay (about two miles above Fish Water) similar rocks appear below the Table Mountain series, dipping 40° towards W., 30° S. The narrow quartz veins which are so abundant in the Malmesbury beds furnished many of the quartz pebbles to the Table Mountain series, and at the unconformable junction visible at Priems Bay, the quartz veins are seen to be cut off at the contact.

* Ann. Rep. Geol. Com. for 1903, pp. 144–146.

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Quartz schists, composed mainly of quartz grains and the micaceous mineral called sericite, are exposed on the right bank of Olifant's River, between the Hol River mouth and Vleermuis Klip, and to the south of the granite boundary on Drooge Kraal. The Olifant's River quartz schists probably lie in a synclinal fold above the limestones, but several miles of sandy ground intervene between the Ko Kenaap limestone and the quartz schists south of the granite.

The Granite Intrusions.

There comes into our area the southern end of a huge mass of granitic rocks, which probably extend some hundreds of miles beyond our limits. It is part of the Bushmanland granite mentioned on pp. 30-33 of the Annual Report for 1900. From the higher points in our district, such as the peak on Louis Fontein (Klein Kogel Fontein Berg) and the Nieuwerust hills, one can see the characteristically-shaped granite kopjes as far to the northwards as the eye can follow them, and they certainly point to the continuity of the Kamies Berg mass with the southern granite area. In Mr. Dunn's geological sketch maps of South Africa, published in 1872, 1875, and 1887, the extent of this group of intrusions, termed gneiss in the reference, is indicated, though it is obvious that the boundaries there given are only broadly represented. In the Report for 1900, we came to the conclusion that the intrusions were older than the Ibiquas group, but we had no evidence bearing on their relationship to the Malmesbury beds. The work in the western part of Van Rhyn's Dorp has upheld the opinion just referred to, and has demonstrated the fact that the Malmesbury beds were invaded and metamorphosed by the granite.

Mention has already been made to the occurrence of phlogopite in the yellow marble from a well at Klip Drift Extension; in addition to phlogopite, there are minute specks of a black mineral which marks paper, and which is probably graphite. The mica schist from the same well consists almost wholly of quartz and mica. Both biotite and muscovite are present, but the former is by far the more abundant. Felspar was not determined, thought it is quite possible that it was overlooked, as only one thin section has been made from the rock (1237). To the west of Klip Drift Extension the junction of the granite and Malmesbury beds is concealed by sand for great distances, but the contact was observed on the west side of the road from Ko Kenaap to Drooge Kraal. The rock next to the granite here is an impure quartzite, that has much the same appearance in a hand specimen as the neighbouring granite, which is fine-grained at the periphery. Some porphyritic crystals of felspar, however, occur in the fine-grained granite. The granite has a streaky structure, and contains numerous angular lumps of the quartzite

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within five feet of the contact. The layers in the granite seem to be due to slight differences in the proportions of the three chief constituents—felspar, quartz, and brown mica—and they are parallel to the surface of the quartzite, giving the section the appearance of a breccia overlain by sandstone. Several granite veins penetrate the quartzite, but these veins are of small size, rarely exceeding four inches in width. The blocks of the quartzite in the granite were, no doubt, divided from the main body of quartzite by the sort of wedging-off process shown in the wall now exposed. A thin section of the altered sandstone, taken from within an inch of the granite, shows that a great development of felspar has taken place, or that some of the granitic material permeated the sandstone. The rock (1238) is composed largely of quartz, but at their edges the quartz grains interlock with each other or with felspar in much the same manner as in granulites. The felspar is of two kinds—orthoclase and microcline; the microcline forms rather larger patches than the untwinned form. Small flakes of biotite and muscovite are present. Small elongated but rounded grains of zircon and apatite occur at places, but they seem to be original constituents of the sandstone, for when the same minerals are seen in the granite, they have good crystal faces.

West of the Drooge Kraal contact, the junction between the two formations was not seen.

The strike of the Malmesbury beds changes from its usual direction, a few degrees west of north, in the neighbourhood of the granite. Along the Moed Verloren Valley they strike east of north, and south of the granite of Drooge Kraal, the beds trend nearly west-north-west, parallel to the direction taken by the granite boundary, and they dip away from it. The exposures are far too few and meagre to decide the general behaviour of the granite at the contact, but it looks as though the granite intrusion had pushed the beds upwards and aside to make room for itself.

Taking the granite mass which comes within the district as a whole, it is a biotite granite, with a tendency to foliation. The localities at which the rock is a massive granite without any parallel arrangement of its constituents over a large area are few, and they are mostly kopjes which project prominently from the surface. Kom Kas Kop is made of massive granite, which crops out in great curved surfaces, that are kept bare and free from vegetation by the splitting off of curved slabs along cracks roughly parallel to the surface. This process also goes on in the rocks with a distinct but not highly developed gneissose structure, and may be seen on any of the conspicuous "kops" or "klips" in the Harde Veld. The hills, such as Olifant's Foot, Krakeel Klip, Oskop, etc., which are inserted on the granite area in the map accompanying this report, all show the roughly concentric breaking up of the coarse gneissose granite.

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In many places there are patches of coarse granite without a trace of foliation lying within the gneiss, but there is no sharp limit between them. The rock with porphyritic crystals of orthoclase always shows a parallel arrangement of those crystals, which lie with their broad tabular faces parallel to one another. This variety of the granite is frequently devoid of any other streaky structure, but the further development of that structure is brought about by the collection of the dark mica or hornblende into lens-shaped masses lying in the same direction as the tabular orthoclase when that mineral is present. Accompanying this change there is also a general parallel arrangement of all the minerals as individual grains, but a marked separation of the various minerals into zones or bands rich in particular varieties does not take place, thus banded gneiss is very feebly developed in this district. Throughout the southern part of the Hardeveld the granitic rock crops out only on the tops and steep slopes of the hills and in the beds of the streams, which are, however, very few in number. In the numerous valleys without a perceptible stream bed there are no exposures, and the nature of the underlying rock can only be ascertained where wells have been sunk. In every case which came under my notice the rock met with under the sandy floor of the Hardeveld valleys is much weathered gneiss, in which the parallel arrangement of the constituents is more strongly marked than in the granite of the kopjes. The presence of foliation undoubtedly enables the weather to break down the rock more rapidly than would be the case otherwise. In those districts the chief destructive agent is the more or less regular and great change of temperature which takes place twice a day. The rocks with a marked parallel structure yield to the strains set up in their component minerals more readily than do those which have no such arrangement. This is evident from the experience that it is much more difficult to obtain a fresh specimen of the foliated than of the massive rocks of the same composition, and it is to be expected, when we consider that in each grain of felspar quartz or mica the expansion due to heating is greater in one direction than in others, so that in the case of the rock with parallel arrangement of its minerals the strains are more likely to act in the same directions than in a massive rock, thereby producing a greater disruptive effect.

The numerous varieties of granite and gneiss, due to the preponderance of one mineral or to the degree of perfection in the development of parallel structure, only have individuality as hand specimens, considered apart from their occurrence in nature, for there are in each case numerous stages connecting the extreme variety with the average type.

There are other varieties of rock in the granite area which are separated from the latter by sharply defined planes, and which occur either in dykes or as irregularly-shaped bodies. Some of

these are practically identical in mineral composition with the granite, but they have a porphyritic, granitic, or microgranitic structure, and they show no parallel arrangement of their constituents; others, again, are widely different in composition, being largely composed of hornblende or augite.

When the report on the district including the granitic rocks under the Langeberg,[1] was written there were no thin sections of the rock available for microscopic examination, and the minerals were not determined in any detail. The thin sections are now prepared, and as the Langeberg granite is part of the same mass as that in the Hardeveld, some account of the nature of the rocks will be given here.

The strike of the foliation planes in the gneissose portions of the granite is usually constant over fairly wide areas, but the same strike is not maintained throughout the district. At the southern end the foliation trends about N. 20° E., but on the hills near Drooge Kraals Poort it varies between north-east and north-west. Near Pot Kley it turns round to N. 50° E., and between the Groot Graafwater hills and the Karree Berg it is E. 15° S., or nearly east. Along the eastern boundary of the granite north of Nieuwerust the foliation planes strike north-east, but to the west of the main road to Garies it retains the N. 20° E. strike of the southern portion of the district, with a tendency to approach north and south. In the Langeberg district the gneiss has a nearly east and west trend, thus agreeing with some of the easternmost occurrences in this area.

It is only in the extreme south at the Drooge Kraal boundary that there is a streaky structure parallel to the wall of sedimentary rocks, though along the Moed Verloren River the divergence from the enclosing wall is not great. Near the boundary north of Pot Kley there is always a great difference in direction, and in many places the foliation planes are nearly perpendicular to the limit of the gneiss. This is often partly due to the presence of a fault, for the rock invaded by the igneous mass is not seen in the neighbourhood.

The constituent minerals of the granites, excluding those bodies of rock which are separated from the main mass by sharply-defined boundaries, are quartz, orthoclase, microcline, oligoclase, or andesine; biotite, muscovite, hornblende, monoclinic pyroxene, garnet, apatite, magnetite, and sphene. The quartz frequently shows strain shadows, and is an abundant constituent, only in the foliated rocks containing pyroxene from the Langeberg area does it decrease considerably in amount.

The most abundant felspars are orthoclase and microcline, which are intimately associated. In a rather coarse grained gneissose rock from the werf at Kom Kas (1244, 1251), a variety

(1) Ann. Rep. Geol. Com. for 1900, pp. 21. etc.

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that is probably typical of the greater part of the Hardeveld, the orthoclase and microcline sometimes form parts of the same crystal, and of the same half of a Carlsbad twin. They build up porphyritic crystals, as well as a later generation without crystalline boundary. In this rock, as well as in other granites from this district in which it is present, the plagioclase fills irregular spaces between the other constituents, and, judging from sections cut perpendicularly to the twin planes, it belongs to the oligoclase-andesine group. A plagioclase also occurs intergrown with orthoclase and microcline, and forms microperthite in this rock and in several others from which sections have been cut. Micrographic intergrowths of orthoclase or microcline and quartz are found in the Kom Kas rock, though only in small portions of the thin slices. Similar intergrowths of those minerals have been noticed in the majority of the Hardeveld granites examined. The biotite is present in much greater quantity than muscovite, though the latter is rarely quite absent from the granites of this area.

The biotite is a strongly coloured greenish-brown variety, in which the deep colour interferes considerably with the brilliance of the polarization tints when the mineral is seen between crossed Nicols. It decreases in quantity as the amount of hornblende increases.

Hornblende is present in very small quantity in the Korn Kas rock, but at other places, such as Quagga's Kop, it is very plentiful, and is accompanied by a very few small crystals of mica (1252); muscovite is not seen in the Quagga's Kop rock, and quartz is less abundant than in the biotite-granites, but the microperthite and oligoclase are more plentiful than usual. The hornblende occasionally shows prism and clinopinakoid faces, but it is usually rather raggedly developed. It is strongly pleochroic in blue-green, olive-green, and yellowish tints. It perhaps belongs to arfversonite, a variety of amphibole; it is not accompanied by glaucophane, a blue amphibole which occurs in some of the gneissose rocks of Prieska. Apatite, iron ores, zircon, and sphene occur in the Quagga's Kop rock. It is noteworthy that no such masses of amphibolite or hornblende-schist as occur at other places in this granite area could be found in the neighbourhood of Quagga's Kop, where the hornblende-granite occupies a considerable tract of country.

At Roode Berg some hornblende rock was found, but it is of a different nature from that at Quagga's Kop. The rock is pale-green in colour, and is repeatedly veined by a coarse-textured pale granite, which seems to play a similar part with regard to the hornblende-granite as pegmatite veins do with regard to many other granites. The rock is found near the southern end of the schistose area west of Nieuwoudt's Naauwte and Driekuil. In the field the outcrops have a distinctly schistose appearance, and I took the rock to be a schistose granu-

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lite containing augite, similar in all respects to the Bitter Fontein granulite (see below), but an examination of the specimens (1258) I brought away shows that this was an error, and that they are much more nearly related to the normal granites of the district. The hornblende is bluish-green and less strongly pleochroic than the Quagga's Kop mineral; it forms larger grains than any other constituent, and shows undulose extinction; it has quite irregular boundaries. The quartz also shows undulose extinction, and areas in the thin section that were evidently once uniform crystal grains are now made up of a minute mosaic of quartz. The felspar is mostly altered, but remains of the original crystals show that much of the felspar was oligoclase or an allied variety. A small amount of biotite is present, and much white mica of secondary origin. Calcite and epidote are abundant.

On the farm Bitter Fontein there is a band of green augite-granulite at least 400 yards wide traversing the coarse biotite-gneiss of that neighbourhood. The band stretches nearly north-east, but I was unable to ascertain its relation to the granite. It is composed of pale green augite, quartz, microcline and orthoclase, the latter being the less abundant, apatite, much sphene in irregular grains, and some epidote of secondary origin; some green hornblende, apparently derived from the augite, is also present (1253). The structure is granulitic, and none of the constituents show idiomorphic forms. There is no garnet in this rock, though that mineral is abundant in some peculiar schists in the immediate neighbourhood, and is not rarely seen in the ordinary biotite gneiss of the Hardeveld.

Rhombic pyroxene has not been observed in the Hardeveld, but it is abundant in some bands of granulitic rocks which lie between layers of garnetiferous gneiss in the Langeberg at the north-east corner of Van Rhyn's Dorp and the adjacent part of Calvinia. In one of these bands the rock has a granulitic structure, but the grains are slightly longer in one direction than in others, and they are arranged parallel to one another. The constituents (753) are quartz, a plagioclase felspar, or more probably two varieties, one andesine and the other a more basic mineral, biotite, hornblende, magnetite, enstatite, calcite, and apatite; the minerals are written down in the order of their relative abundance, but there is little difference between them in this respect till the enstatite is reached; both it and the apatite are much less frequent than the preceding minerals. None of the minerals (except the apatite) have idiomorphic forms. The hornblende is a deeply coloured olive-green variety, and the pleochroism is strong. The biotite is red, and strongly pleochroic. The enstatite is colourless, and has partly been altered to a green serpentinous mineral. The apatite is often completely enclosed by all the other minerals, except calcite, and is the only one which shows crystalline boundaries. Calcite

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fills up sharply defined spaces between other minerals. A few small crystals of zircon are enclosed by the felspar and biotite. No garnet or monoclinic pyroxene occur in this rock.

A rock from Ezel Kop Vlakte, in the same neighbourhood, but some 14 miles south of the Langeberg, has a similar structure to that just described, but there is less magnetite and apatite, and a considerable quantity of pale green augite. The rhombic pyroxene is a pleochroic hypersthene in place of the colourless enstatite. The hornblende, biotite, iron ore and apatite are similar to the same minerals in the Langeberg rock (765).

The only other rock containing hypersthene known to me from the west of the Colony is a copper-bearing rock from Nababeep, which is, in part at least, composed of hypersthene, a basic plagioclase, magnetite, and bornite. The hypersthene is identical in character with the hypersthene of Ezel Kop Vlakte; the bornite is easily distinguished from the magnetite in thin section under the microscope by its colour by reflected light. The Nababeep rock is also granulitic in structure. Bornite has not been observed in the hypersthene-granulite from Ezel Kop Vlakte.

The bulk of the granitic rock in the Langeberg region is a garnetiferous gneiss in which the felspar is orthoclase, oligoclase, or a microperthitic intergrowth of orthoclase and a plagioclase, but microcline is very rare. Both biotite and muscovite are present.

The contact between the pyroxene-granulite and the surrounding rock in the Langeberg region is perfectly sharp, but the minerals of the two interlock so that the rock breaks as readily across the contact as along it.

In the bed of the Klein Goerap River there are good exposures at frequent intervals between Kom Kas and the Zout River, and a better idea of the relationship of the various members of the granitic series can be gathered from these sections than from a wider area of country with more isolated outcrops. The total length of the portion of this valley below Kom Kas Kop is about 12 miles along the bends taken by the river and 10 miles in a straight line. For a distance of about six miles below Kom Kas the only rock seen is a rather coarse biotite gneiss, occasionally with porphyritic crystals of orthoclase; this rock is similar to that described on a previous page from the werf at Kom Kas. In the poort traversed by the river on Klein Goerap, which is about half a mile long, many varieties of gneiss, depending upon slight changes of mineral composition, can be seen: but they are not always sharply separated from each other When the difference between the varieties in contact depends upon the size of the constituent grains it is found that the finer grained rock penetrates the coarser as a rule, the exception being in the case of very coarse pegmatitic rocks, which only occur in thin veins traversing all the other varieties. There is in the

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poort a thick band of dark hornblende-gneiss traversing a rather fine grained grey biotite gneiss, which in its turn is sharply separated from a coarse porphyritic gneiss. The hornblende gneiss is well foliated as a whole, though in a hand specimen the foliation might not be noticed, and it is in part banded by the collection of the hornblende and biotite into thin layers. From the main band of hornblende gneiss many finger-like streaks penetrate the grey gneiss, parallel to the foliation of both rocks, but the foliation planes are locally greatly disturbed and contorted without any sign of fracture, in such a way that could only have been brought about while both rocks were in an almost liquid condition. Under the microscope the rock (1245, 1246) is seen to consist of quartz, orthoclase, oligoclase, hornblende, biotite, garnet, apatite, and magnetite, with a few decomposition products. Some of the biotite seems to be of secondary origin, but some of it is certainly an original constituent. Apatite is the only mineral which shows crystal outlines. The hornblende occurs in large irregular patches and also in minute grains in a mosaic with quartz, giving the appearance of an intergrowth in ordinary light, but the different grains of the two minerals do not act as parts of large individuals. In the case of this rock there can have been but slight difference in age from that of the surrounding gneiss, and it seems likely tnat both underwent slow, but irregular movement during the final stages of their consolidation.

Further down the valley a number of outcrops of deeply weathered fine-grained gneiss or felspathic mica-schists are seen The foliation is less marked than the schistose structure, and it is possible that these rocks may be of metamorphic origin. They are traversed by lenticles of coarse pegmatitic rock, which resist the weather better than the enclosing schists or gneiss. The rocks were too much weathered for cutting thin sections from, but felspar, quartz, biotite, and muscovite are amongst the components. Lower down, near the Salt River, red and grey biotite gneisses are met with.

Traversing the gneiss of this part of the Hardeveld there are several dykes of basic rock of much later age described on pp. 31, 32.

On the Salt River above the mouth of the Klein Goerap River there is a curious hornblendic rock, forming an irregularly bounded lenticular outcrop lying roughly parallel to the foliation of the gneiss; the greatest width of the outcrop is 100 feet, and the length about 400 feet. The rock (1241) is composed of deeply coloured green hornblende in long prismatic crystals which may show prism and pinakoid faces. The pleochroism is in olive-green, blue-green and yellowish-green tints, and the mineral is easily fusible before the blow-pipe; it agrees with the variety of amphibole called arfedsonite. This mineral is quite fresh and unaltered, but it is imbedded in a mass of saussurite, a decomposition product of plagioclase, and leucoxene, an

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alteration product of ilmenite. A greenish biotite is also present, and the long sections are bent. The contact with the surrounding rock is sharply defined.

The irregular patches of amphibolite in the gneiss of Klip Drift Extension are of various compositions. One variety (1234) is made up lamost entirely of greenish-brown hornblende, which is less pleochroic than the amphibole of Quagga Kop and the Salt River rock; a very little partly altered plagioclase is present, and also iron ores, leucoxene, apatite, and reddish biotite in small flakes enclosed by the hornblende. Another variety (1233), which occurs in the manner shown on the accompanying plan (fig. 2), consists chiefly of tremolite in irregular ragged patches, enclosing very irregularly bounded grains of colourless augite. The tremolite has a large quantity of opaque iron ore granules arranged along its cleavage planes, and also in broad zones which do not follow a particular direction in the crystal; the tremolite is at places altered to a colourless and almost isotropic serpertinous mineral along its cleavage; the edges of the patches of tremolite are often much clearer than the central portion, owing to the absence of iron ores, and they show the cleavage cracks less distinctly; there appears to have been a re-growth of tremolite round the original patches. The augite is present in much less quantity than the tremolite; it has poorly developed cleavage, and is comparatively free from inclusions of iron ore.

These amphibolites are separated quite distinctly from the surrounding gneiss, which is a fine grained biotite-gneiss. They remind one of the basic patches in many granites, but they are of much greater size than the basic patches in the Paarl and Malmesbury granites. The largest patch of amphibolite I saw is the one sketched in fig. 2, and it measured at least 8 feet by 4, the length must, however, be greater than 8 feet. The greater diameter of the figured amphibolite outcrop does not lie in the direction of foliation of the surrounding gneiss.

The second of the above varieties of amphibolite scarcely shows any parallel arrangement of its constituents, but the first variety has a distinctly schistose structure, owing to the vertical axes of the crystals lying in more or less the same direction.

Along the Graauwe Duinen Coast there are occasional bands of fine-grained granulite intercalated with the rather coarse pink granite which is exposed for several miles on this part of the shore. The granulite forms bands up to 350 feet thick, but it weathers more rapidly than the granite, and some of the sandy bays with no outcrops may be caused by the presence of still wider masses of granulite. The strike of those observed was about west-south-west. The junction with the pink granite is sharply defined in places, but there are so many thin layers of granulite lying parallel to the larger bodies that the junction tends to be a zone rather than a line; the thin layers of granulite may be of extreme tenuity. In addition to the granulite

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layers in the granite, lenticular streaks of the latter occur in the former, so the relation of the two rocks is very intimate, and is difficult to explain, on the supposition that one is later in date than the other. The granulite (1256) consists of quartz, orthoclase, microcline, oligoclase, biotite, and muscovite, and has a typically granulitic structure; the biotite is strongly pleochroic in very pale yellowish tints to deep brownish green.

A somewhat similar granulite was found at Bitter Fontein in connection with the schistose rocks on the eastern part of the farm, but there is less microcline and no white mica in this rock.

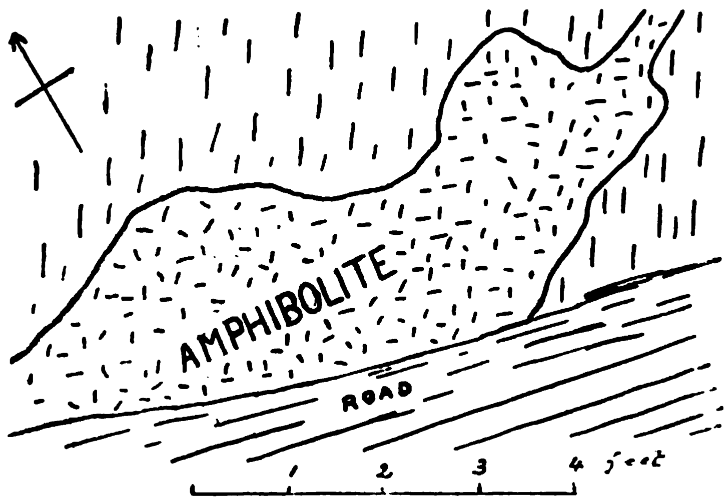

Fig. 2.—Plan of amphibolite outcrop on the road through Dooge Kraal's Poort. The rock surrounding the amphibolite is gneiss; the direction of strike of the foliation planes in the gneiss is shown by the short lines. No amphibolite occurs on south side of the road.

The grains of the constitutent minerals are separated by very narrow zones of sericitic material, except in the case of the contact between two grains of quartz. All the grains show signs of movements after consolidation, the extinction never being uniform throughout a grain.

In the hills made of schists on the north boundary of Roode Berg there is a quartz rock of rather peculiar character, which I took to be a vein of quartz of the same general nature as the numerous white or translucent quartz veins in this district. An examination shows it to be composed of quartz, magnetite ,and muscovite, and to have a sub-granulitic structure (1259). No

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felspar is visible, and the muscovite is present in small proportion but is sufficiently abundant to be visible in the hand specimen. The magnetite has no crystalline form, but fills up irregular spaces between the quartz grains. The individual quartz patches are fairly uniform in size, and have a form more nearly resembling that of the quartz in granulites than the intricately interlocking quartz crystals of massive quartz veins. The rock appears to be related to the intrusive masses of this district rather than to the abundant quartz veins.

In several places veins of fine-grained granite traverse the coarser rock, whether that rock be a normal granite or a gneissose granite. The most noticeable character of these fine-grained rocks is their poverty in the ferro-magnesian constituents, biotite and hornblende. A specimen from a fine-grained vein in the massive granite of Valsch Gat's Kop consists of quartz, microcline, orthoclase, and oligoclase, with a very little biotite; magnetite and sphene are also present, but apatite, a rather abundant constituent of the Hardeveld granites, is absent (1260); the microcline and orthoclase occur together as intergrowths.

Quartz-porphyries are not nearly so frequently met with as in the granite areas of the south of the Colony, but they do occur. A few boulders of a felsitic rock with porphyritic quartz and orthoclase lie in a stream bed on Drooge Kraal, but I could not discover the parent mass. On Kogel Fontein, Louis Fontein, and Zout Fontein, north of Salt River, there is a dyke of quartz-porphyry 150 feet wide in places traversing the gneiss in a nearly east-south-east direction for a distance of at least six miles. The foliation of the gneiss here strikes about N. 10° E., so the dyke cuts across the foliation nearly at right angles. The rock consists of a ground mass of quartz and orthoclase, partly microgranitic and partly micropegmatitic in structure; grains and crystals of quartz and orthoclase are embedded in the ground mass, which always has a micropegmatitic structure in their neighbourhood; in many cases the optical orientation of the quartz in the intergrowth is the same as that of the quartz in the porphyritic crystal, but it is not invariably so.

At Riet Fontein, on Salt River, there is a mass of very silicious gneiss associated with the coarse biotite gneiss of the neighbourhood. The latter rock is composed of quartz, oligoclase, orthoclase, biotite, and apatite; the felspars from perthitic intergrowth, and the orthoclase also occurs in small patches of micropegmatite. The more silicious rock contains but little felspar, which is orthoclase and microcline, and a small quantity of biotite and apatite. The line between the two rocks is quite sharp, but it was impossible to determine their mutual relation with certainty. It is probable that the silicious gneiss is an igneous rock, intermediate in composition between the normal gneiss and the very acid vein on Roode Berg mentioned above.

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THE SCHISTS IN THE GRANITE OF THE HARDEVELD.

These rocks make up two ranges of low hills on the eastern part of Bitter Fontein. Their strike is W. 30° S., parallel to the foliation of the enclosing gneissose rocks. They include mica schists, quartz schists, and a gneissose rock containing a large amount of sillimanite and cordierite. They are veined by layers of ordinary gneiss along their strike, and present a series of wedge-shaped ends in the gneiss at the south-western extremity of the hills. Towards the north-east they are cut off by a north and south fault, along which the weathered slates probably belonging to the Ibiquas group are thrown down against them. The quartz schists, mica schists, and quartzites of these hills present no characters calling for special attention, but the sillimanite-bearing rock is an interesting and peculiar member of the group. It is a coarse-grained rock in which garnet, felspar, quartz, biotite, and sillimanite are visible to the naked eye. The sillimanite occurs in two forms, (1) as very thin acicular crystals embedded in felspar, and (2) as unusually large prismatic crystals bounded by prism faces, with well-developed cleavages parallel to the macropinacoid; the latter are best seen in transverse sections, but they are obvious in some vertical sections; the crystals are jointed transversely. The cordierite is recognisable by the pleochroic halos round inclusions and by its alteration to a greenish substance in which the halos persist. Garnet is very abundant. The felspar is chiefly microcline. The mica is present in large flakes. Quartz is not very abundant. There is a little magnetite or other iron ore. All the minerals are much cracked, except the mica, which is bent, and the cracks are filled with an alteration product. The sillimanite is the only constituent with idiomorphic forms; it is wrapped round by the other minerals.

Sillimanite-cordierite schists have not been recorded from the Colony hitherto, nor from other parts of South Africa, but a fibrolite- (sillimanite) gneiss has been described from Sievenberg, Hereroland.[1] There is, however, no close resemblance between the two rocks, as the Sievenberg gneiss does not contain garnet, and the presence of cordierite is doubtful, while the sillimanite is only found in the acicular form.

The sillimanite-cordierite gneiss of Bitter Fontein is closely associated with the obviously metamorphic rocks of the neighbourhood, but it is more nearly allied in mineral composition to the granites that surround them.

(1) H. Wulf. Beitrage zur Petrographie des Hererolandes in Südwest Afrika. Tschermak's Mittheilungen, VIII., p. 13 of separate copies). Vienne, 1887.

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Basic Dykes.

In the district under consideration basic dykes are uncommon, and all that I met with were in the granite area, though I was informed that a dyke rock, similar to the one described below from Nieuwerust, crops out on the farm Spitzberg amongst the quartzite of the Nieuwerust series.

In a well sunk into the gneissose granite of Nieuwerust a doleritic dyke was met with. In a hand specimen this rock has much the same appearance as one of the finer grained dolerites of the Karroo type; under the microscope it is seen to be rather more altered by weathering than most Karroo dolerites. The chief constituents are basic plagioclase, of which a part at least is labradorite, and augite, biotite, and magnetite are present in much smaller amount, and colourless and green hornblende and a serpentinous mineral are secondary products. Olivine may have been present in irregular grains, now represented by the serpentine. The augite forms small and partly idiomorphic crystals, and also irregularly-shaped masses between the felspars, though this commencing ophitic structure is not developed further (1261). A small amount of quartz may be present in the ground mass, but much of the latter is felspathic. This rock is closely related to the dolerite in the thinner dykes and sheets of the Karroo, though it has not the strikingly porphyritic structure found in the thinnest doleritic intrusions of that region.

In the poort cut by the Klein Goerap River some four miles above its mouth there is a dyke of doleritic rock 10 feet thick traversing the gneiss in a direction bearing 10° north of east. Porphyritic crystals of plagioclase up to 1-10th inch in length and dark green patches of chlorite or other alteration product are visible to the naked eye. In thin section (1247) it is seen to be a porphyritic dolerite without olivine. There is a great amount of calcite in the rock. The porphyritic felspars are slightly zoned, and they are labradorite, the ground mass felspars are less basic, according to the angles of symmetrical extinction, but still they are near labradorite. The augite is largely changed to a greenish mineral. Biotite is present in numerous small flakes. There are many vesicles filled with chlorite, or chlorite and calcite.

Lower down the river there are three more dykes, composed of two varieties of rock. One variety has the appearance of a fine-grained Karroo dolerite, but examination of a thin section (1248) shows that it is a considerably altered rock. There are pseudomorphs of calcite and another colourless mineral after a porphyritic constituent, possibly olivine. The rest of the rock is sub-ophitic in structure, labradorite crystals and a rather strongly coloured violet augite in irregular wedges between them. There is very little biotite in this rock, but a large amount of magnetite and ilmenite. This rock was vesicular, but calcite and chlorite fill the vesicles

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The second variety has a dull green colour, and under the microscope it is seen to be (1250) a mass of felted, ill-defined crystals, which behave like felspar between crossed nicols, so far as their properties can be ascertained, with very minute granules and flakes of greenish and opaque substances whose nature is uncertain.

A dyke of this second variety is also seen in the bed of the Salt River just below the entrance of the Klein Goerap River, and it is there cut by a dyke of rather peculiar character. This later dyke is a blue rock with a fine-grained ground mass containing large flakes of biotite, which may be as much as an inch in diameter; there are also many inclusions of pink felspar, quartz, and gneiss. The biotite does not belong to the gneiss.

Under the microscope a thin section (1249) shows porphyritic crystals of a monoclinic pyroxene, and pseudomorphs of calcite (or magnesite), and a serpentinous substance after olivine. The ground mass is composed of grains and small crystals of the same variety of pyroxene as occurs in porphyritic crystals, biotite, iron ore grains, and an ill-defined base containing calcite, a very small quantity of felspar, and some glass. The felspar is in minute and irregular patches, but the twinning seen under a high power is sufficiently characteristic. The pyroxene is an almost colourless variety, but it has a slight purple tint; it behaves in a peculiar manner between crossed nicols, it is zoned, and there is incomplete extinction in polarized light, for the crystal or grain shows a dark blue colour at one position and a dark brown when moved very slightly across the position where extinction should be observed; this is due to the very strong dispersion, augite containing much titanium is said to have this property. The biotite occurs in plates of all sizes, from an inch in diameter to the most minute flakes visible under the microscope, but the larger plates are not sufficiently abundant to prevent the largest sized individuals from giving the rock a very peculiar appearance. The specific gravity of a specimen containing some inclusions of granite is 3·009, which indicates a still higher density for the rock without inclusions. Mr. J. Lewis, of the Government Analytical Laboratory, made a determination of the silica percentage in some fragments of the rock chosen on account of their freedom from granitic inclusions; the percentage was 39·5. This rock belongs to an unusual type, which has not been recorded from the Colony previously, and whose relation to the known rocks of other countries must remain uncertain until a complete analysis has been made.

The Ibiquas Series.

The rocks belonging to this group lie between the Bokkeveld escarpment and its prolongations to the north and south on the one hand and the Hardeveld granite and the Malmesbury beds south of it on the other. The nature of the boundary between

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the Ibiquas and Malmesbury series has already been discussed (see p. 14), so it is unnecessary to repeat all the facts bearing on the question. The strongest evidence for the unconformity of the two groups is the occurrence of pebbles, apparently derived from the Malmesbury beds, in the Ibiquas conglomerates and grits. It should be noted also that while these grits are almost in contact with the limestones of the Malmesbury beds on Klip Fontein, and probably also on Groot Kobe, to the north-west of Zout River a great thickness of sericitic slates, belonging to the Malmesbury beds, intervenes between them.

Near the Bokkeveld escarpment the strike of the Ibiquas beds lies between 10° and 20° west of north, but further west it becomes more nearly north-west, being usually about N. 40° W.; north of Spitz Berg the strike varies again, becoming more northerly.

In Calvinia these beds were found to be faulted down against the Bushmanland gneiss,[1] and it was regarded as probable that the latter was much older than the Ibiquas group, and furnished the granitic material in the grits and conglomerates. It was stated that the fault is concealed westwards of Ezel Kop Vlakte under the red sand that covers so much of that country. The present work has not covered the area between the north of the Knegt's Vlakte and Ezel Kop Vlakte, so the north-western part of the Ibiquas boundary has not been examined. On Nieuwoudt's Naauwte the Ibiquas beds and the unconformably overlying Nieuwerust beds are faulted down against the schistose rocks of Bitter Fontein, and on Spitz Berg against the granite inlier of Springhaan's Kloof. Both these faults affect the Nieuwerust beds, but on the south-western corner of Bushman's Grave there is a fault, also with downthrow on the Knegt's Vlakte or east side, separating the Ibiquas from the granite, and it is cut off by the later fault affecting the Nieuwerust beds of Karree Berg, with downthrow in the same direction. The Bushman's Grave fault bends round in Flamink Vlakte, and is concealed beneath the south-eastern portion of Flamink Berg. South-east of Flamink Berg the Ibiquas beds are in contact with the Malmesbury beds along what is, at least in part, probably an overthrust fault. There is no evidence to show that the boundary faults north of Karree Berg are overthrusts.

We thus see that the Ibiquas beds in Van Rhyn's Dorp and Calvinia occupy an area of depression with regard to the older rocks to the north and west of them. Whatever effect this structure had on the topography of the area in remote ages it was obliterated before the deposition of the Dwyka conglomerate in Calvinia and the Table Mountain series in Van Rhyn's Dorp, for both these formations lie unconformably and undis-

(1) Ann. Rep. Geol. Com. for 1900, pp. 28 29 and 33.

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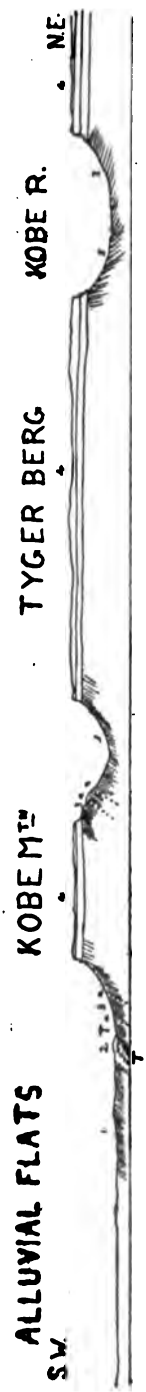

Fig. 3.—Section through the Kobe Mountain. 1. Malmesbury beds, sericitic slates. 2. Malmesbury beds, limestone. 3. Ibiquas beds. a. Beds of conglomerate and grit. 4. Table Mountain Sandstone. T. Thrust fault. Horizontal distance, 13 miles; vertical scale, $\frac{1}{10}$ in. to 974 feet.

turbed upon the junction of the Ibiquas beds with the gneiss in the one case and the Malmesbury beds in the other; while the Nieuwerust beds also of Pre-Cape age, of Flamink Berg and Karree Berg pass uninterruptedly over the Ibiquas beds and the granite on either side of the Bushmen's Grave fault.

The absence of metamorphic changes in these beds near their contact with the Harde Veld granite is as marked as it is in the Calvinia district. At one place in a ravine leading from Flamink Berg to the Flamink Vlakte the two rocks are exposed within a few feet of each other; beyond the disturbance and fracture of the sedimentary beds due to the faulting, there is no difference between the beds here and those of a similar nature in other parts of the Knegt's Vlakte.

The Ibiquas beds in this district are slates, grits, and conglomerates. The sandstones which form such a conspicuous part of the group north of Vuur Fontein and behind Stink Fontein Poort are not met with here; they appear to be confined to the upper part of the series. The slates often have much sandy matter in them, but, as a whole, they are much more argillaceous than the sandstones higher in the series. Much of the slate is very argillaceous, and weathers to variously coloured clays. In the western part of the area the slates become markedly sericitic within a few feet of the larger quartz veins of the older generation, a result of the dynamo-metamorphism produced by the great disturbance of this portion of the area. The quartz veins themselves are broken, and have silvery films of sericite on the fractured surfaces. The later quartz veins described on p. 40 are not accompanied by these phenomena.

The grits and conglomerates are well developed along the western border of the area occupied by this series. The conglomerates on Quagga Kraal contain larger pebbles than those seen on Diep Kloof (Onder Kloof) and Vuur Fontein Extension. Where the Geelbek's River cuts through a thick band of

conglomerate on Quagga Kop[1] the rocks are well exposed. The chief rocks which occur as pebbles in these conglomerates are grits, quartzites, sericitic slate, quartz, granite, gneiss, quartz-porphyry, and crystalline limestone. A thin section of one of the Vuur Fontein Extension conglomerates (787) shows that the gritty matrix is largely composed of grains of quartz and felspar, with white mica in small flakes; the rock fragments include more than one variety of felspathic dyke rock in addition to quartz schist, granite, marble, vein quartz, and slate. One of the felspathic rocks is of similar type to the green dykes of Klein Goerap and Salt Rivers. Another specimen of conglomerate, from Diep Kloof (786), contains a large amount of calcite, and a piece of crystalline limestone in it shows distinct traces of oolitic structure.

On the farm Diep Kloof (Onder Kloof) a band of conglomerate crops out three times between Lion's Head and Tyger Berg, being repeated by folding. One of these outcrops ends abruptly against crushed slate on the nek over which the path to Groot Kobe lies.

No fossils were obtained in the Ibiquas beds, and there is nothing new to say about their relationship to other Pro-Cape rocks in the Colony.

In the great area presumably occupied by the Ibiquas beds on Knegt's Vlakte there are very few outcrops; the surface is a sandy soil with numerous fragments of vein quartz and fewer of slate weathered out from the underlying rock. The Geelbek's River has a wide sandy bed, with occasional outcrops of slate. The smaller stream beds that I saw had no outcrops in them.

THE NIEUWERUST SERIES.

In the neighbourhood of the post-office station called Nieuwerust, on the Namaqualand road, there are groups of rather large hills formed of arkose, quartzite, and slate, of later age than the Malmesbury beds, granite, and the Ibiquas series.

As these rocks are quite different from all the other sedimentary rocks in this district, and as they cannot yet be correlated with any formation described from other parts of South Africa, they will have to be called the Nieuwerust beds. In 1900, during a survey of the extreme north-eastern portion of Van Rhyn's Dorp, two outliers of this formation were found on Slag Kop near Groot Klip.[2] It was then thought that these outliers might be the bottom beds of the Ibiquas group, as they lay upon the granite north of the fault along which the Ibiquas beds are thrown down (on south side) against the Bushmanland granite.

(1) This "Quagga Kop" is a large tract of country on either side of Zout River near the bridge, it has nothing to do with the Quagga Kop in the Harde Veld mentioned previously.

(2) Ann. Rep. Geol. Com. for 1900, p. 30.

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There is, however, no doubt that this opinion is wrong, for there is no rock quite like the Slag Kop beds in the Ibiquas group, and the latter certainly pass under the arkose of Flamink Berg unconformably. The Slag Kop rock has a close resemblance to parts of the Nieuwerust beds.

This group covers but a small proportion of the area, but on account of its difference from the other formations it is of importance, and there is no doubt that it extends far into Namaqualand. The ranges composed of it have a characteristic appearance, which enable one to distinguish them from the granite and gneiss hills at a great distance. From the tops of the hills near Nieuwerust one can see the characteristically stratified rocks in the hills far to the north. The horizontality of the beds is one cause of these appearances, and another is the strongly marked lithological difference between successive thicknesses of the rocks; in the case of hills formed of the Malmesbury, Ibiquas, or Table Mountain series the strata are more uniformly attacked by the weather.

The two most characteristic lithological varieties in this group are the comparatively soft arkose and the quartzitic arkose. The soft arkose occurs at the base of the formation in the hills east and south-west of Nieuwerust and in Flamink Berg. It is composed of quartz and felspar fragments, with occasional flakes of mica. There is so close a resemblance between the products of weathering and soils derived from this rock and those derived from the granite and gneiss that in the absence of actual outcrops it is often impossible to determine on which formation one is at a given spot. Where a path or road traverses the veld, the part of it on granite is distinguished by little black streaks of magnetite lying in the runnels made by water; the arkose contains little or no magnetite, and these streaks are not seen on the paths that lie on this formation. The soft arkose is easily attacked by the weather, and a good example of the fresh rock was not seen during this survey; even on the hill east of Nieuwerust, where an excavation has been made for the purpose of obtaining building-stone, the rock at a depth of four feet from the surface is much weathered. The felspar is dull and crumbles to small fragments; there is little black mica or other ferro-magnesian constituent. The soft arkose would have a very close resemblance to the porphyroids of the Cango were the felspars less decomposed. The rocks containing less felspar than the soft arkose, become harder; there is every intermediate variety between the soft arkose and intensely hard quartzites, bluish in colour, with very little or no felspar in them. Where the felspar is present in small quantity the bulk of the rock is made up of quartz grains, and these are cemented together by the deposition of silica between them, so that the rock is a quartzite. The felspar in the quartzites, though seen to be cloudy when examined under the microscope, is much

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less altered than the same mineral in the soft rocks; orthoclase microcline, microperthite, and a plagioclase have been noticed in a thin section of one of the quartzites.

Some thin beds of conglomerate occur in this group. The pebbles noticed were made of quartz and granite, and they were embedded in a sandstone or quartzite matrix. Only at one place, the western foot of Flamink Berg, were the conglomerates seen at the base of the group; elsewhere they are interbedded with the arkoses and quartzites at various horizons. The thickest bed of conglomerate met with was little more than three feet thick. The beds of conglomerate are not extensive; those that were followed round the hill slopes disappeared within a few hundred feet. Argillaceous beds do not seem to be abundant, but this may be partly due to concealment of outcrops under débris. In a river cutting south of the Spitzberg hills there are bands of shale exposed varying from 10-50 feet in thickness. These rocks are bluish grey sandy shales, occasionally becoming more argillaceous, and they have thin quartzites interbedded with them. The sandy shales are very strongly false bedded, more so than the quartzites. The surfaces of the quartzites are frequently ripple marked. In the hill east of Nieuwerust the section through the beds is as follows:—

Quartzites	15 feet
Quartzitic arkose	50 „
Quartzites	20 „
Arkose	30 „
Quartzitic arkose	70 „
Quartzites...	25 „
Shales	30 „
Arkose at base of the formation ...	90 „
	330 feet

At the north end of the Karree Berg group, on a hill called Thomas Kits Berg locally, the following descending section was obtained:—

Hard blue quartzite	40 feet
Quartzitic arkose	65 „
Hard blue quartzite	15 „
Quartzitic arkose	170 „
Conglomerate	2 „
Arkose with a shale band 18 ft. thick in middle	100 „
Conglomerate	3 „
Arkose	90 „
	485 feet

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The above sections were taken at places where the rocks lie nearly flat and are well exposed on precipitous hillsides. It is probable that more than 500 feet of rock is present in the hill west of Groot Graafwater, but that hill is not a convenient place for measurement on account of the dip of the strata and the distance of the highest point from the exposed base of the formation.

The junction with the granite and gneiss is clearly seen at several places on the farms Springhaan's Kloof and Spitzberg, Oor Kraal, Bushman's Grave, and Flamink Vlakte. On Springhaan's Kloof the hills immediately east of Nieuwerust rise steeply above a small valley, and a tongue of Nieuwerust beds projects south-eastwards from the large mass occupying the southern part of Driekuil. The arkose at the base of the formation here rests upon an old denuded surface of the granite. At the north end of Karree Berg and along the east and north flanks of Flamink Berg the unconformity is admirably exposed. At the summit of the nek over which the main road passes between Flamink Vlakte and the valley leading southwards from Nieuwerust through Oor Kraal the junction with the gneiss is clearly seen from the road. About a mile south-west of this nek the base of the series is conglomeratic and contains subangular and rounded fragments of the gneiss set in a dark felspathic grit. This conglomerate is about two feet thick, and it is succeeded by 150 feet of rather soft arkose, and this again by hard blue quartzites with little felspar in them. The thick arkose was followed southwards beyond the gneiss area on to the Ibiquas series, but the actual junction between these two groups was not seen in section. Flamink Berg slopes down to a line of low hills, and ends almost imperceptibly, and the contact with the Ibiquas beds is covered with soil. There is a very marked change in dip as one traverses the southern end of Flamink Berg. The occasional outcrops of slate and grit belonging to the Ibiquas group have a high dip, sometimes approaching the vertical, but the Nieuwerust beds are inclined at a very low angle. The general form of the boundary line between the two formations certainly favours the supposition that there is an unconformity between them. From the western boundary of Nieuwoudt's Naauwte to Spitzberg and thence south-east to Bushman's Grave the Nieuwerust beds are bounded by a sinuous line following the contour of the ground, and to the east a long gentle slope covered with gravel and soil descends to the river bed on the western side of Knegt's Vlakte; in some of the kloofs cut into this slope the Ibiquas beds are laid bare, slaty rocks with a constant high dip towards a point a few degrees south of west; the Nieuwerust beds have a low dip, rarely exceeding 15°, to the south-west. On Spitzberg there is a gap of rather over a mile from which the Nieuwerust beds have been re-

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moved and where the Ibiquas beds are in contact with the gneiss along a fault.

On the southern part of Springhaan's Kloof and the north of Oor Kraal the Nieuwerust beds have been denuded away, and the underlying granite and gneiss are exposed at the surface; a small outlier of arkose alone remains.

The south-western boundary of the Drie Kuil-Karree Berg mass of Nieuwerust beds is in part defined by a fault trending W. 20° N., parallel to the fault which party cuts off the Spitzberg and the north end of the Karree Berg areas, and which also separates the Ibiquas group from the gneiss on the farm Spitzberg. The south-western part of the boundary from Nieuwerust to the northern part of Roode Berg is probably an unconformity. At the extreme northern end of Roode Berg there is another fault, directed nearly north and south, along which the Nieuwerust beds are thrown against the granite and schistose rocks.

The Flamink Berg-Groot Graafwater mass is nearly cut in two by a fault running N. 25° W. through Oor Kraal; a continuation of this fault bounds the small outlier south-east of Nieuwerust on its south-west side. The Groot Graafwater hills are made of Nieuwerust beds resting upon Malmesbury beds along their southern and eastern borders. The actual contact has not been seen, but along the Groot Graafwater River at Donker Gat the crumpled phyllites belonging to the Malmesbury beds are exposed at the base of the high hills to the west, and the quartzitic arkose with a low easterly dip is met with on the hill some 50 feet above the level of the river bed. The phyllites are also seen in a well on the same farm. The south-western boundary is formed by a curved fault or a group of faults extending from the eastern side of Pot Kley to near Booy's Berg.

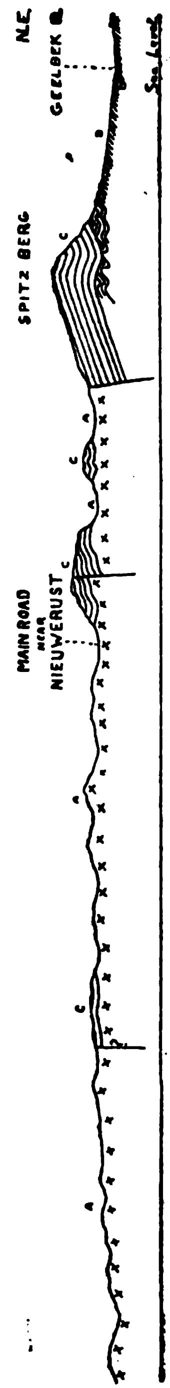

Fig. 4.—Section through the hills formed of Nieuwerust beds, near Nieuwerust. A. Granite and gneiss. B. Ibiquas series. C. Nieuwerust series. Scale: horizontal, 1 inch to 2·8 miles; vertical, 10 times as great; about $\frac{1}{10}$ in. to 150 feet.

A considerable outlier of the Nieuwerust beds occurs on Elands Hoogte; it extends in a north-easterly direction for some four miles. The south-western boundary is a fault, at least in part, and the continuation of this fault is marked by the great quartz vein on Mierhoofd Kasteel.

Most of the boundary faults are occupied by veins of white quartz, which make very conspicuous features in the landscape. These veins occur along the faults in the Karree Berg, Driekuil, Oor Kraal, and Mostert's Kop (Malmesbury beds and granite) boundaries. It is probable that a large vein on Varskop is also a fault vein, though the throw cannot be determined on account of the similarity of the massive gneiss on each side of the fault. The quartz of these veins is easily distinguished from that in the older veins in the Malmesbury beds by its white colour and the small proportion of material other than quartz. The distinction from the quartz in the small veins in the Ibiquas group is not so obvious, and they may be of approximately the same age. The fault-veins reach a considerable thickness, over 300 feet at Mierhoofd Kasteel, and quite 300 feet on the south-west flank of the Karree Berg group near the nek on the west of Bushman's Grave. Where the veins are very thick they contain pieces of the rock on either side of the fault, and are really due to the repeated filling of a widening fissure. In places the loose textured rock belonging to the Nieuwerust beds is charged with quartz along a band near the veins.

An outlier of Nieuwerust beds forms the hill called Meulstein Berg on the farm Nabeep; as the name implies, millstones have been obtained there. In the Hardeveld there are several pairs of millstones from Nabeep in use, and they are preferred to imported stones, as they are said to retain their surfaces longer.

It is impossible at present to decide the relationship of the Nieuwerust beds to the sandstones of Namaqualand[1] and those of the Huib and Han Ami plateaux in German South-west Africa. It is worth noting here that the limestones that overlie the nearly horizontal sandstones both in Namaqualand and Damaraland are not known to be represented in the Nieuwerust area.

The Table Mountain Series.

This formation takes but a small part in the geology of our district; it occurs on the eastern limit and near the mouth of the Olifant's River. There is nothing to add to the account of the sandstone on the Bokkeveld escarpment given in the Report for 1900.

Near the mouth of the Olifant's River the Table Mountain series is met with between Fish Water on the south bank and

(1) Wyley, A. Report upon the Mineral and Geological Structure of South Namaqualand, etc. Cape Town, 1857, pp. 5 6.

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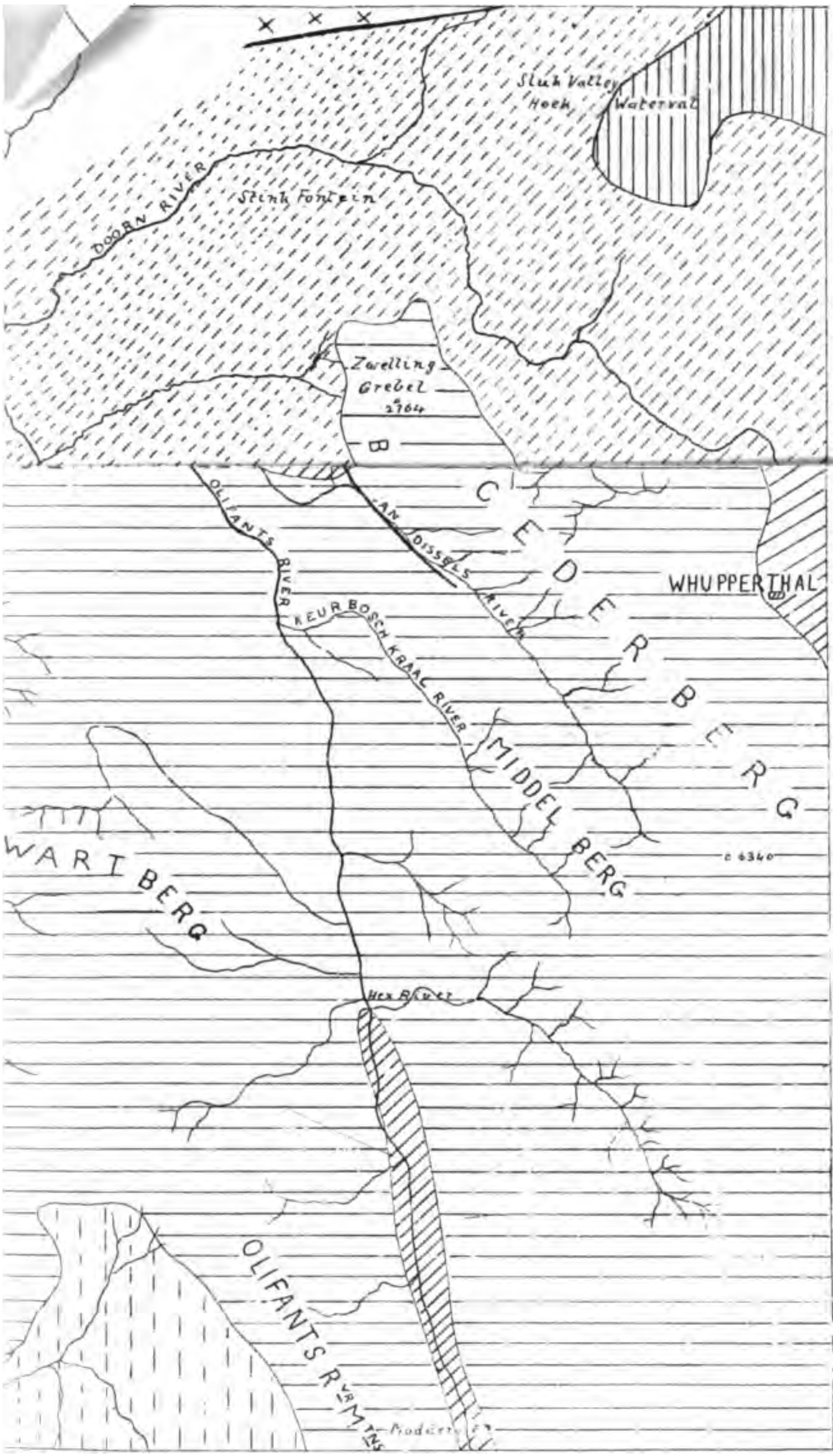

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Elsie Erasmus Kloof. It is the north end of the immense area of sandstone in the west of Piquetberg, Clanwilliam, and southern Van Rhyn's Dorp, and terminates in the Sand Veld on the farms Drooge Vley and Klip Drift, though the boundary is entirely concealed there. The rock crops out on the coast near Clift Point, and it may be seen in several places in Elsie Erasmus Kloof, but it is usually covered by the sand.

On the left bank of the Olifant's River near Priem's Bay (about 4 miles above Fish Water) the unconformable junction with the Malmesbury beds is exposed. The latter are cut to a fairly level surface, and on it rests the Table Mountain series. The base of the series is a conglomerate about 6 feet thick, composed of quartz pebbles set in a reddish sandy matrix. Thin lenticular layers of sandstone without pebbles lie in the conglomerate. About 6 feet above the base the rock becomes less conglomeratic and at a height of 15 feet above the base, the usual type of sandstone, with occasional quartz pebbles scattered through it, is seen. On the right bank the unconformity is not so well exposed.

The outcrops near the Olifant's River show that this northern tongue of sandstone is slightly folded, a central anticline is flanked on either side by synclines. The observed dips do not exceed 8°.

Volcanic Neck in the Kobe Valley.

On the northern part of Keerom in the Kobe Valley the Kobe River has cut a cliff through a large mass of agglomerate. The cliff is about 70 feet high, and presents a remarkable appearance to one who approaches it from up-stream; the matrix is dark red, becoming almost black on long exposed surfaces, and through it are strewn promiscuously pieces of granite, gneiss, quartzite, crystalline limestone, and other rocks up to 8 feet in diameter. These fragments are angular or subangular in form. Some slate blocks were found with the red matrix in numerous patches, chiefly along the cleavage planes, as though the block had been shattered after it reached its present position, but before the matrix became hard. Though the rock as a whole can be said to have no regular arrangement, there are streaks of the red matrix, without fragments of granite, etc., passing in various directions through the main mass of agglomerate; these have a nearly vertical dip. The rock crops out in the bed of the river at several spots above and below the cliff, and at places on the steep mountain slopes on either side. The slopes are well covered with bush and débris fallen from the upper parts and the sandstone cliffs which crown them, and during my visit I was unable to make a thorough examination of the locality, so the following account of the size and relationship of the occurrence is incomplete. The agglomerate appears to occupy a pipe in

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the Malmesbury beds, and is flanked on the north-east and western sides by crystalline limestone of the Aties beds which are much disturbed and twisted out of their normal strike on the south-western and north-eastern borders of the pipe. The northern boundary is obscured, and I was unable to follow up the southern edge. The dimensions of the cross sections of the pipe, so far as the observed outcrops allowed them to be estimated, are 460 yards from north to south by 600 from east to west; the former figure is likely to be too low.

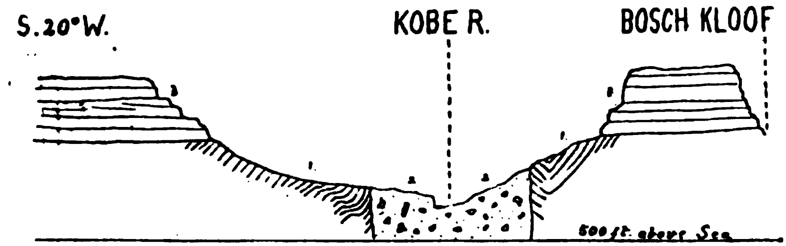

Fig. 5.—Section through the agglomerate pipe on the Kobe River. Vertical and horizontal scale, 1 inch = 2,500 ft.
1. Malmesbury beds.
2. Agglomerate of pipe.
3. Table Mountain Sandstone.

In the northern portion of the outcrops the rock is somewhat different in character from that described above. It is greenish in colour, and contains fewer large fragments of rock, but the same varieties of rocks occur in it as in the red breccia, with the addition of much greenish chlorite both in fragments of an altered basic rock and in the ground mass.

In thin section the matrix of the red rock is opaque; fragments of granite or gneiss and of their component minerals, quartz, orthoclase, microcline, microperthite, and biotite, and pieces of crystalline limestones and quartzites are embedded in it. These inclusions are quite fresh, and show no signs of weathering or other form of alteration; there are also a few small fragments of a yellow serpentinous mineral. The inclusions in the greenish rocks of the northern outcrops are the same with the addition of the chloritic rock.

The crystalline limestone is very similar to that of the Aties beds, and was doubtless derived from them. No granite or gneiss crops out in the Kobe Valley, and one has to travel some 35 miles to the west before one reaches the outcrop of the Hardeveld granite. The presence of such large and numerous blocks of granitic rocks in the agglomerate indicates the existence of an intrusion at no great depth under the valley. The quartzites and grits met with in the breccia cannot be identified, possibly some of them may have been derived from the Table Mountain and Ibiquas series.

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The position of the pipe, in the middle of the deep valley cut by the Kobe River, is such that direct evidence of its relation to the Table Mountain series is not obtainable, and, therefore, the only proof of its age is the fact that it traverses and contains fragments of the Malmesbury beds. The absence of crushing and deformation of the contained boulders shows that it is very probably of later age than the Ibiquas beds, for the conglomorates and grits along the western edge of the latter formation have been greatly disturbed. The close resemblance to those agglomerates in the Saltpetre Kop necks[1] which are made up chiefly of fragments of sedimentary rocks is very striking, but the large plates of mica and other minerals derived from deep seated rocks of basic composition which are found in several of the Sutherland vents have not been observed in the Kobe neck. The latter is much more like the Sutherland agglomerate necks than any other known occurrence of breccia in the Colony, and though actual proof of their community of age and origin cannot be expected they may conveniently be placed in one and the same group of volcanic phenomena. It may also be observed that the remarkable grit dyke on the farm Elands Vley[2] is made up of a material somewhat similar to the greenish rock on the northern side of the Kobe pipe.

RECENT OR SUPERFICIAL DEPOSITS.

In this district the time between the formation of the Table Mountain sandstone and the sands and gravels of quite recent origin is unrepresented by any sedimentary deposits. The Bokkeveld Witteberg, and the whole of the Karroo beds are wanting, and there is no trace of the Uitenhage series.

In some of the gravels and raised beach deposits in Van Rhyns Dorp there are so many boulders of various rocks which are frequently found in the Dwyka conglomerate[3] but are not known to occur in situ in this district that I expected to find an outlier of the conglomerate west of the Bokkeveld escarpment, but it was not found.

The gravels lying upon the Malmesbury and Ibiquas beds at many places along the Zout and Varsche Rivers contain a large proportion of boulders foreign to the district, and some of these consist of hard Dwyka conglomerate such as is met with near the intrusive dolerite along the edge of the Calvinia plateau. The other foreign rocks were certain varieties of granite, amygdaloidal diabase of the Zeekoe Baard type, and chert; these are all abundantly represented in the Dwyka conglomerate of Calvinia, and were doubtless derived from it. Some of the

(1) Ann. Rept. Geol. Com. for 1903, pp. 43-67.
(2) Ann. Rept. Geol. Com. for 1900, pp. 17-18.
(3) Ann. Rept. Geol. Com. for 1903, pp. 162-3.

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boulders in these gravels are a foot long, and the large boulders occur at the base of the gravels; the rock becomes much less coarse above, and passes into sandy silts or yellowish sand. The whole thickness of the gravels and sandy material varies greatly; along the river banks from 10 to 30 feet are usually seen, but on part of Zout Fontein on the right bank of the Zout River there seem to be quite 100 feet of these deposits. They cover a wide area between the Hardeveld granite and the Troe Troe River, but north-east of the farm Zand Veld they are not sufficiently developed to warrant their being mapped as a separate group of deposits. South of the Troe Troe they decrease rapidly in importance, and are not distinguishable from the thick sandy soil that hides the Malmesbury slates in that neighbourhood.

A remarkable feature in the alluvial silt exposed along the belt of country from the Troe Troe below Aties to the Zout River opposite the entrance of Groot Graafwater River is the amount of gypsum (sulphate of lime) in it. The gypsum is often sufficiently abundant to make the sandy alluvium hard; it is intimately mixed with the rest of the rock, and does not form thick layers of gypsum separated by beds of other material, though thin lenticles containing only a small amount of sand in proportion to the gypsum present have been observed. It is likely that the sulphate of lime is a product of the mutual decomposition of calcite and pyrites in the Aties beds, and that it has been brought to its present position by water rising to the surface of the ground during dry weather.

Gypsum occurs in other surface deposits in the district, but it is nowhere so abundant as in that portion of the area underlain by the Aties beds. In the sandy soil along the Klein Goerap River there is enough gypsum to attract the attention of a person walking over the ground, especially where the soil is exposed in ravines. The underlying rocks here are gneiss and granite, in which calcareous and pyritic minerals are not conspicuous, but the gypsum is probably derived from the decomposition of those rocks, for the drainage basin lies entirely within the area occupied by them.

The thick sandy silt was probably deposited by the present streams at a time when the general surface of the country was at lower level than it now is. The streams now run in steep sided valleys, along which sections up to 100 feet in height show that the upper part of the ground is made of the sandy silt and the lower of Malmesbury or Ibiquas beds.

Surface-quartzites are found in the country between the Hardeveld and the Olifant's River.

On the right bank of the Hol River, about a mile above its junction with the Olifant's, there is an outcrop of surface-quartzite about 30 feet above the river bed; the quartzite passes under the sand and gravel exposed at the edge of the slightly inclined plain which slopes from the Moed Verloren Hills to the

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Olifant's River. The quartzite varies from one to fifteen feet in thickness in the course of an outcrop 100 yards long. This rock, as is usually the case, has different characters in different parts of the outcrops; some portions are extremely close-grained and break with a conchoidal fracture, others are coarser, and include pebbles and angular lumps of vein quartz, but there are many gradations between the two extremes. The rock often contains irregularly-shaped cavities of small size; they rarely exceed a tenth of an inch in length.

On the right bank of Olifant's River at Kliphuis an unusually thick bed of surface quartzite is exposed, and it has evidently been cut back by the river. The layer is at least 30 feet thick, possibly more, as the lower slopes are covered with fallen blocks; a similar thickness of surface quartz is seen on Elsie Erasmus Kloof, and a few intermediate outcrops lie between the two localities, which are about six miles apart. That these outcrops do not belong to one continuous deposit is proved by the absence of the quartzite from some deeply cut ravines in which the sand and gravel, that cover the surface generally in this neighbourhood, lie directly upon weathered slates. The quartzites are met with in many isolated outcrops on Drooge Valley and Schaap Vley, where the rock is surrounded and probably in part buried under the sand.

The facts noticed in this district are in agreement with earlier observations on these surface quartzites, in that they show that the rock forms isolated patches, and that, except on mountainous ground, one never knows where it may occur. It has not been found to occur under certain conditions only. It is probable that the quartzites along the Olifant's River extend below sea level; they are at most five feet above high tide level on Elsie Erasmus Kloof.

In places highly ferruginous layers are met with below the surface sand and gravel. On the left bank of Hol River, opposite the outcrops of surface-quartzite mentioned above, there is an irregular layer of ferruginous nodules occupying a corresponding position to that of the surface-quartzites on the right bank.

No special examination of the surface-quartzites and ferruginous rocks has been made, and there is nothing to add to what has appeared in previous Reports concerning their genesis.

Surface-limestones are abundant in this area, and there is often a thin layer of impure limestone immediately underlying the soil in the area occupied by the Aties beds. This limestone is evidently derived from the underlying crystalline limestone by solution and redeposition of the carbonate of lime by percolating water.

There are no consolidated sand dunes in Van Rhyn's Dorp, though on Elsie Eramus Kloof and the Olifant's Heights small patches of calcareous sand blown inland from the coast are in places converted into a hard rock owing to cementation by car-

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bonate of lime. These are, however, only a few feet in length, and are hardly comparable to the hardened sand-dunes of Saldanha Bav and Bredasdorp.

WATER.

The greatest need in the Hardeveld and the country between the Hardeveld and the Bokkeveld Mountain is a permanent water supply. Springs are extremely few, and practically the whole of the present supply comes from wells, dams, and the small depressions weathered out of solid granite. The purposes foı which water is urgently needed are watering stock and domestic use. Some houses roofed with corrugated iron have tanks for the collection of rain water for domestic use; the well water is too brak for this purpose, but it is well suited for stock, and a greater amount more widely distributed is required. At present there are many farms which have to be abandoned for several months at a time owing to lack of water, though were a moderate supply available the veld would carry stock throughout the year.

There are no rainfall records for the Hardeveld, but it appears that the district receives more rain than the country round it, for the veld is usually in better condition. Most of the rain that falls is absorbed by the soil, for the streams that drain the area are few and small. The solid granite is not a favourable rock for the storage of water, but where a parallel structure is well developed, as seems to be the case in the rock underlying the valleys, the rock is deeply weathered. The weathered granite and gneiss take in water, and moderate supplies are likely to be obtained by boring. It is unlikely that water will ever flow from a bore-hole in this material, but valuable supplies could be obtained by pumping. Springs occasionally issue from the immediate neighbourhood of the great white quartz veins traversing the granite; these veins act in a similar manner to the dolerite dykes in the Karroo; they form impermeable walls traversing the rock nearly vertically, and the underground water on that side which lies higher is brought to the surface at the outcrop; even where no spring occurs in such a situation the vegetation on the higher side of the vein is found to thrive during a drought along a zone several yards wide.

There may be areas in the dry Knegt's Vlakte which will yield water through bore-holes, but as a whole the rocks appear to be too argillaceous and close-grained, and the conditions are not so favourable as in the Hardeveld. There is, however, so great a need for water at different places in the Vlakte that a few holes should be put down in order to test the country. It must be remembered also that the rocks are hidden over large areas, and it is possible that in places they may be of a more favourable character than those on which the above statement is based.

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THE GEOLOGICAL SURVEY

OF THE

LONG KLOOF

BY

E. H. L. SCHWARZ.

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THE GEOLOGICAL SURVEY OF THE LONG KLOOF.

By E. H. L. Schwarz.

The following report is a continuation of the study of the folded mountain region in the south central districts, which has already been described by me in the Report on Knysna, 1899, and the Report on Willowmore and Uniondale, 1903. The small scale map on p. 52 will show the extent and complexity of the whole area.

The Long Kloof is a narrow strip of habitable country lying within the folded mountain region between the coast and the Karroo. It is approximately one hundred miles long, beginning on the west, a little west of Doorn River on the George-Oudtshoorn road, and ending on the Kromme River Heights, on the boundary between the Divisions of Uniondale and Humansdorp. The form of the "kloof" is continued far to the east into the Humansdorp Division, and nearly to the village of Humansdorp itself, but the eastern part of the valley lies much lower and warmer, and loses the sour cold aspect of the Long Kloof proper, and the Dutch settlers, with their wonted good eye for the country, are right in limiting the term to the district to the west of the headwaters of the Kromme River. Adjoining the Long Kloof there are side kloofs, known as the Kouga and Little Long Kloofs, and indeed the Long Kloof itself is not a single valley, as the name would seem to imply, but a succession of narrow valleys, markedly disconnected at various points, both in respect to their extension lengthwise and to their breadth. In last year's Report there was given a description of Baviaan's Kloof, which is a "kloof" lying similarly within the mountains, and separated from the Long Kloof by the Kouga Mountains; that district was described as a succession of fold and fault valleys, and the Long Kloof may be said to be the same, only the folding has not been so intense, and therefore the valleys are not so deep.

The rocks with which we shall be concerned in this report belong almost entirely to the Table Mountain and the Bokkeveld series. The latter is the cause of most of the valleys being habitable, as the soil derived from the Table Mountain sandstone is usually so poor that ordinary crops will not grow upon it unless artificially manured, or unless supplied with a rainfall very much more abundant than that with which the Long Kloof is supplied. The rocks of which the Bokkeveld series is made

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up, include shales, calcareous sandstone, and occasionally black limestones, and though white sandstones, apparently free from lime, do crop up, it will be found that these in their unweathered state do contain a notable percentage of lime. In many of the folds which build up the mountains the crushing has been so intense that the Table Mountain sandstone in the synclines has pushed out the slates of the Bokkeveld series, and the top bed of sandstone in one limb is closely pressed against the top bed in the other. Where the Bokkeveld slates have been included in the syncline, there are to be found the Long Kloof valleys, for the rocks, consisting largely of argillaceous and calcareous materials, have been more affected by the action of dissolvent water than the sandstones and quartzites of the Table Mountain series. Soft zones in the sandstone occur, and also produce valleys; I believe, too, that there are actually calcareous beds in the Table Mountain sandstone, although I cannot refer to any analysis to confirm my opinion, but the unwonted presence of Aloes in some of the hills near Misgund seem to point to the fact. It is, therefore, in places difficult to ascertain whether a particular valley is underlain by slates of the Bokkeveld series, or whether it is merely a valley eroded along a loose sandstone band in the older series. In the low lying ground the rock is usually covered with detritus, and there are seldom outcrops sufficiently large to determine definitely the nature of the valley rock.

The detritus is usually derived from the disintegration of the Table Mountain sandstone, and the great preponderance of this series over the Bokkeveld slates would render the soil sour and unproductive, were it not for the great fall of the rivers, which carry the sand away and allow the calcareous and argillaceous rocks in the valleys to contribute to the making of the soil. As a rule, the sub-soil is gravel, consisting of angular sandstone fragments often somewhat water-worn, and thickly coated with iron. The gravel can best be seen in those places where the ground is levelled and the soil washed away, for there has been a time when the drainage of the Long Kloof was checked, and the mountain torrents, instead of collecting and passing outwards to the Kouga River and thereby to the sea, as they now do, seem to have been held back by rock barriers, and to have formed great marshes, or, as they are called in South Africa, "vleis." From this cause the whole of the Long Kloof exhibits a "bevelled" appearance, that is, the lower ground rises to the mountains on either side by low-grade slopes, which the present rivers cut into deeply, and on these slopes there are the vlei-deposits—ironstone gravel and fresh-water quartzite. In traversing the Long Kloof, there is no gradual rise from one end to the other, such as exists in the Baviaan's Kloof or the valley of the Clanwilliam Olifant's River, for the Long Kloof has no river of its own,, and the mountain streams gather together and

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traverse the bounding mountain ranges by deep poorts, so that the Long Kloof may be said to consist of a succession of basins formed by the head-waters of tributaries of the two great rivers, the Kouga, belonging to the Gamtoos System, and the Kammanassie, belonging to the Gouritz System. The actual head of these two great rivers lies half-way through the Long Kloof, so that the traveller going in at one end of the kloof rises gradually till he comes to the centre, at Avontuur, and then descends till he comes out at the other end.

The feature that characterises the Long Kloof above everything is the high level gravel-covered bevels or terraces cut in the valleys, and which meet in the centre between the two boundary ranges of hills. All stages in their formation and destruction can be seen. They are still forming in some places owing to the rock-barrier which holds back the waters being still sufficiently resistant to withstand the corrasive action of the rivers, so that the latter pour out of the Long Kloof by great waterfalls, and the ground above forms extensive palmiet marshes, with low-lying alluvial ground adjacent; at others the barrier is just giving way, the marsh is being drained, and the gravel and fresh water quartzite that has formed beneath the stagnant waters, border the sides of the bank; at still others the barrier has long given way, and the bevel is left high and dry, so that the sides of the brook are bordered with kopjes capped with a layer of hard gravel, quartzite, or cemented river-wash, inclined at a gentle angle away from the hill-side. A great deal of the solid geology is, therefore, covered by recent deposits, and the nature of the underlying rock cannot be determined by the sort of soil that exists on the surface, for though it is a general rule that the soil in the Table Mountain sandstone is poor, and that in the Bokkeveld beds rich, nevertheless, owing to the wash of ironstone gravel that has settled over the sour sandy beds of the older series, the resulting soil approximates in appearance to that formed on the slate beds; whether the ironstone gravel has been long left high and dry and has disintegrated into soil, or whether the black vlei soil is still in position above the gravel, the result, as far as its agricultural value is concerned, is much the same, and one finds homesteads situated on the pure sandstone ground, with good corn land and orchards, which would be impossible were it not for the recent deposits.

As regards the structural lines revealed in the Long Kloof, there is one long valley filled with slate extending from the Oudtshoorn-George road in a direction due east. At the farm known as Keurboom's River or Orange Kloof it turns away southwards at about 30° S. of E., and a new slate valley begins and runs due east for some 36 miles, when another main valley begins, and runs with a small inclination to the east and west direction to the Kromme River Heights; here one comes to the

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edge of a gravel-capped plateau, and the Long Kloof proper ends. North of Keurboom's River there is the end of the Kouga Mountains, which run due east, and on the north of these there are folds or structural lines running 30° N. of E., so that, from a point in the neighbourhood of Keurboom's River there is a streaming or divergence of the structural lines (map); in other words, with the main mountains about here running due east and west there is a secondary folding, forming a net-work with the two sets of lines meeting at a little less than 60°. In last year's report on Baviaan's Kloof I found a similar diagonal folding, but attributed the inclination to the interaction of north and south folds, but I now find that the inclination is not a resultant of two lines of forces, but actual direction in which these forces acted.

The Long Kloof of Avontuur drains into the Kouga River, a tributary of the Gamtoos River, but only a small portion of the upper course of the river lies in the Long Kloof: at Haarlem it plunges into a great complex of mountainous ground, and eventually joins the Baviaan's Kloof River. On the north side of the river there are the Kouga Mountains, and deep within these there are two small strips of good ground, known as the Kouga district. These are narrow fold-valleys, formed in a similar way to the valleys in the Long Kloof and in the Baviaan's Kloof, only that the intensity of the folding is intermediate between the two latter. In the easternmost of the two Kouga basins there is a patch of Enon Conglomerate, which although separated on all sides in the peculiar way in which the deposits of this age occur in the Colony, yet is probably the end of a string of similar basins which come west from the great mass in the Humansdorp Division.

The western end of the Long Kloof was briefly referred to in last year's Report, p. 119. The valley begins a few miles west of Doorn River in the George-Oudtshoorn road, but there are no outcrops to give any definite boundary lines, and indeed it is not till the drainage slopes become steep in the neighbourhood of the Keurboom's River that the rock underlying the valley can be seen. I was unable to get any fossils from this portion, and it might be urged that one is dealing not with the Bokkeveld series, but merely with a shaly or soft band in the Table Mountain series, or even with the slates of the Malmesbury series; in the northern branch the valley which carries the Long Kloof beyond Keurboom's River, however, I have found Terebratulas, characteristic of the Bokkeveld beds, in the slates, so that there can be no doubt as to the real nature of the soft rocks in the western portion.

At Schoonberg the mountains on the south side of the valley are increased, as it were, by a ridge added on in front of the main mountains. The anticline of which the ridge in the northern side of the mountains is composed has had pressure applied in

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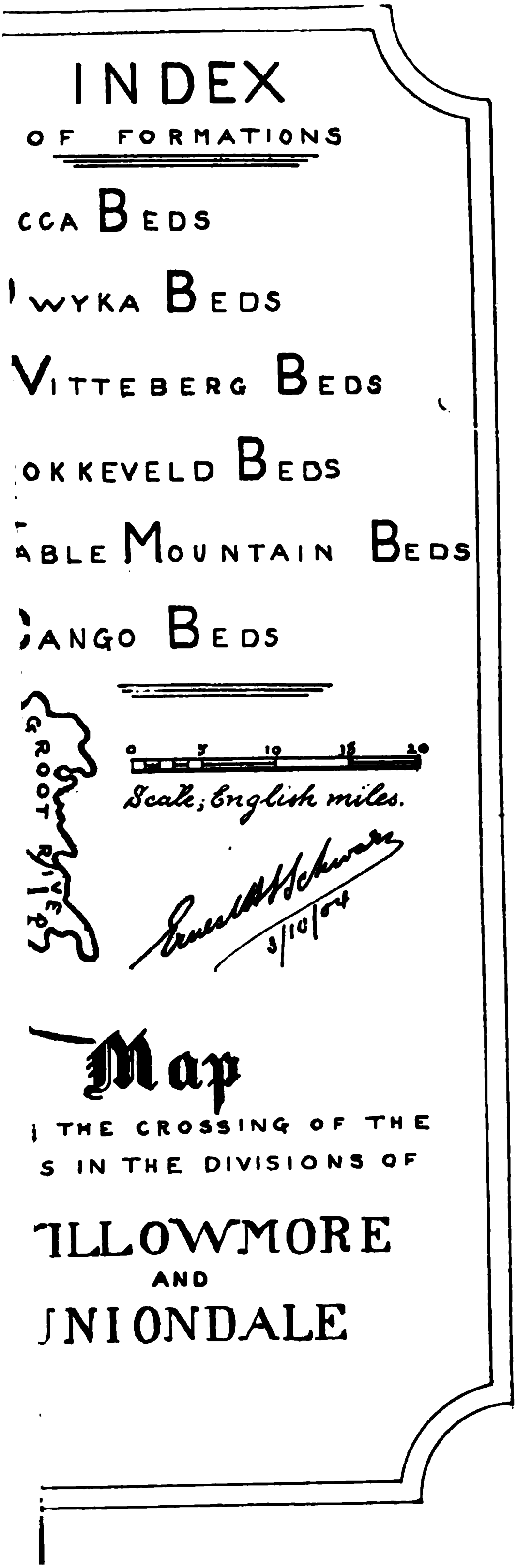

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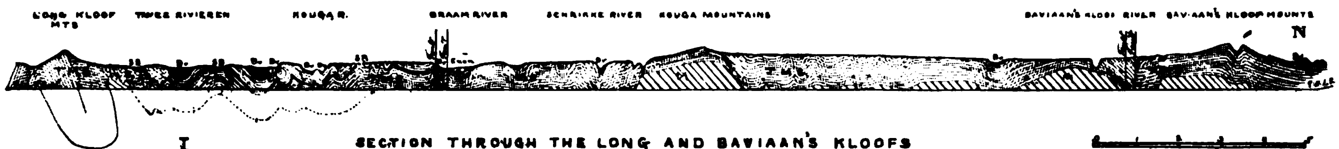
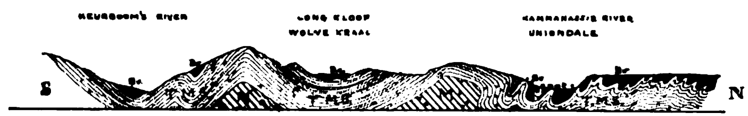


I. SECTION THROUGH THE LONG AND BAVIAAN'S KLOOFS

M. Old Cape Rocks. T.M.S. Table Mountain Series S.S. Shale Band in do Bv Bokkeveld Series ENON Enon Conglomerate

Scale of English miles
Vertical and Horizontal Scales the same in both sections



II SECTION THROUGH THE MIDDLE LONG KLOOF, UNIONDALE

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the direction of its length, and the fold has thereby been forced to buckle. The hills on the northern side of the Long Kloof show this much more clearly than on the south side about here, as only the tops of the anticlines come to the surface and protrude through the Bokkeveld slates; they are also much more drawn out in the north than on the south of the Long Kloof. A more direct way of observing what has happened is by following the course of the shale band in the sandstone. This particular band of shale in the Table Mountain sandstone begins, or, at any rate, is first observable in the George-Oudtshoorn road, near the bridge over the Afgunst River; it may, however, continue to the west through Kouw Douw or Wagenboom's River. It can be followed east through Annex Ezeljagt and round the spur to the Devil's Kop. The rock of which it is composed is here mostly soft sandy material, showing little argillaceous matter, and it is covered with dense scrub of Proteas, Heaths, and sedges. At Devil's Kop it twists north to follow the bent outcrop of the sandstone, and thence can be followed in a long course of narrow longitudinal valleys parallel to the main Long Kloof valley. The side streams that course down from the mountains have taken advantage of the softer rock in this zone, and have excavated these valleys. One is apt to regard them as of the same nature as the main valley, namely, as Bokkeveld valleys, but by Devil's Kop one can see the corresponding shale band on the southern side of the anticline traversing the great series of sandstones exposed on the steep sides of the kloofs, and there can be no doubt that the rocks in both exposures are actually part and parcel of the Table Mountain series. At the farm Klip River, near Keurboom's River, there is the bend which alters the strike of the rock from E. and W. to E. 30° S., and the pressure at this point has caught the soft sandstones of the so-called shale band, and has evidently hardened them sufficiently to make them indistinguishable from the hard sandstones of the series. Once past this point, however, the shale band begins again in its normal condition, and forms a narrow valley parallel with the Bokkeveld slates in the valley of the Keurboom's River —the valley is no longer known as the Long Kloof, owing to the rapid fall of the rivers having reduced the ground to a level below that of the Long Kloof. If there was not convincing proof at Devil's Kop that this band is not composed of Bokkeveld slate, this pinching out of the valley at Klip River would be held as a partial proof that it was made of Bokkeveld beds caught in a syncline; for where the pressure comes in there the syncline would naturally be pushed upwards, and the slates resting in the trough of the syncline would be cut out on a surface that went horizontally across the mountains.

The main valley at Schoonberg is about two miles across, and after the commencement of the new ridge, is about a mile to a mile and a half wide. The whole surface of the ground about

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Schoonberg, Ganze Kraal, Eenzaamheid, and Mill River is flat, and covered with sandy soil underlain by ironstone gravel; the streams pass through the boundary hills on the north, and pour into the main valley of the Kammanassie River by fairly high waterfalls. These streams are working their way backwards, and eventually will drain the Long Kloof about here more vigorously, and allow the ground to be cut into kopjes, which will show the slate beds; the quartzite barriers, however, show every sign of holding good for a very long period still. Even as it is, one set of barriers has evidently given way, for there are table-topped hills capped with ironstone gravel along the sides of the streams Ganze Kraal and Eenzaamheid Huis Rivier, and a more extensive area of the same occurs at Schoonberg; these old river-levels stand some 150 to 200 feet above the present levels.

At the farm Diep Rivier the flat-topped hills stand out very prominently, as they overlook the valley of the Keurboom's River. I think it is very probable that the Diep Rivier streams used to drain into the Keurboom's River, but when the first set of barriers on the north of the Long Kloof were eroded away, the waters were turned into the Kammanassie River system; but now since the new barriers are standing in the way of the outlet of these streams and the Keurboom's River is quite free of such impediments, the latter river is rapidly eating its way back through the slate hills, and will shortly recapture the waters of Diep Rivier; unless the barrier gets worn away more quickly than is now being done, it will in the course of time invade the waters of Mill River and westwards of this.

The main syncline of the western Long Kloof turns away to the south of east, and instead of being characterised by flat ground covered with sandy soil, it is now intersected by steep-sided kloofs exposing the Bokkeveld slates, and the level of the Long Kloof proper is shown on the tops of the hills, which were once all connected, and formed extensive areas of flat ground; the upper valley of the Keurboom's River, in fact, resembles in topography that of the Kammanassie River valley.

At Klip Rivier the southern branch of the main Long Kloof syncline again divides into two portions, one, the smaller, runs up into the mountains about Prince Albert's Pass, but ends before reaching the road; the other turns away to the south-east, past Edmonton, or, as it is still called, De Vlugt. This syncline has not yet been mapped to the end; it may either die out as the northern branch does, or may run far into the mountains to Zoet Kraal. The dip of all the rocks is steeply south, and both limbs of the synclines are practically parallel.

At Diep Rivier the real Long Kloof breaks off, and a small extent of deeply eroded valley extends from Diep Rivier to Gwarina. It is only a narrow strip of Bokkeveld slates, but past Gwarina the deeply eroded nature of the valley comes abruptly to an end

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at the head waters of the Keurboom's River, and the traveller ascends to the level of the true Long Kloof once more. The second portion of the Long Kloof begins with such an insignificant width of shale that one could be at first sceptical whether this is a true Bokkeveld syncline, especially as the sandstone beds on both sides dip south at a high angle, making it appear as if the shales were intercalated with the sandstones; the valley, however, soon broadens out, and characteristic Devonian fossils appear. On the north side of the farm Gwarina the hills of Table Mountain sandstone are folded into a steep anticline, and a ledge is shown in the hill-side as if it were made of softer beds, held in the trough of an additional syncline. I do not, however, think that the throw of the fold is sufficiently great to bring these beds down to the present erosive surface.

At Wolve Kraal the normal high cold veld appears, but the underlying rock appears in the valley, and at one place is full of *Terebratulas*; the rock is a dark blue argillaceous limestone, and the fossils are those that occur to the exclusion of almost all other forms in the Baviaan's Kloof in similar beds. The Wolve Kraal streams gather together and pass through Potje's Kloof to join the Potje's River, and eventually the Kammanassie River; both the main kloof and a side one that come in from the east in the midst of the sandstone hills are extraordinarily deep and steep-sided; that means that the barrier is close up to the Long Kloof valley boundary, and that the course through the sandstone hills has been eroded to nearly the level of the Kammanassie River.

At the next farm, Avontuur, the same happens, but the course of the river through the hills is far longer and the stream that comes in from the east in the midst of the hills is bordered by bevelled flats, which are comparatively thickly populated. As this last river, however, forms the commencement of the Kouga District, it will be described later (p. 59).

At Avontuur we get the watershed between the Gouritz and Gamtoos River systems: to the east along the Long Kloof there are the farms Braam Fontein, Vyge Kraal, and Welgelegen, and then the Mission Station of Haarlem. Along the river which passes through these farms, and which is the commencement of the great Kouga River, the gravel-covered hills become successively more developed, that is to say, at Avontuur one sees undulating sand-covered flats with a gravelly sub-soil; as one travels towards Haarlem the river cuts down through the plain, and reveals the Bokkeveld slates capped with a thick covering of cemented gravel; the village of Haarlem stands on a typical high level gravel flat. At Haarlem the Kouga River gets behind the northern range of hills bounding the Long Kloof, and thence continues right away to its junction with the Baviaan's Kloof River through an almost impenetrable complex of sandstone and quartzite mountains. The reason of this

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is that the next two farms in the Long Kloof, Ongelegen and Misgund, lie at the end of the Bokkeveld-filled syncline; beyond there is a ridge of Table Mountain sandstone, which was at one time levelled flat with certain tracts within the mountains, so that the river had a choice of courses open to it, and, curiously enough, the barriers holding back the waters within the mountains gave way before those in the Long Kloof, and hence the river took the mountain route.

A portion of the farm Misgund, Cambo, Somerset's Gift, Klip Kopjes, and part of Louter Water are on the dividing ridge of Table Mountain sandstone. At Misgund there is a narrow tract of shale; I was unable to get outcrops in the valley, but on the nek along the road to Somerset's Gift there are slates which look like typical Bokkeveld beds; as, however, this tract of slate is continued far to the west on to the Prince Albert's Pass, I am inclined to consider it as the outcrop of the shale band in the Table Mountain sandstone. On the north of the undoubted area of Bokkeveld beds, in Ongelegen, there is a thin tract of shales and soft shales along the Kouga River behind the first ridge of boundary hills, and I think this is the outcrop of shale corresponding to the other on the south. The whole of the rocks by Misgund are extremely closely folded, and several small valleys are produced, which look as if they were occupied by slates; the ground, however, is so covered with soil and gravel-deposits that one is unable to arrive at satisfactory conclusions as to the solid geology.

On Louter Water the third and last of the main Long Kloof valleys begins. The Bokkeveld slates first cross the river and the syncline ends somewhat abruptly in the hill-side on the west bank. There are abundant palmiet marshes along the stream, and where the road crosses the fresh water or limno-quartzite formed under such stagnant water is exposed. The rock is brilliant white quartzite, holding large water-worn boulders, cemented together; there is a smoothness or glassiness connected with this limno-quartzite that distinguishes it at once from boulders of Table Mountain sandstone, which often become white and intensely hard by the leaching out of the iron sulphides that originally coloured the cement between the grains and by the deposition of silica in its place.

In this last Bokkeveld valley in the Long Kloof there is far more complexity than in the others; parallel with the main syncline there are seven long areas of slate, some of which are certainly Bokkeveld slates, and some probably belong to the shale band in the Table Mountain series. Each of these is divided by a tract of Table Mountain sandstone, in places ranging up to a considerable height. There are no fossils to be found in these slates, owing to the ground being so covered with surface deposits, and one is entirely at a loss as to what particular rock a particular valley is underlain by. As a general rule, the rocks

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in the Long Kloof dip south at a high angle, but north of the main valley we are now discussing the rocks lie flat, and then take on a northerly dip. In the main valley lie the farms Krakeel River, Fontein Kloof, Onzer, Twee Rivieren, and Elands Fontein.

Taking a section at Twee Rivieren, we get on the south the Table Mountain sandstone standing vertical; there is a fairly wide valley, on which the bulk of the cultivated lands of the farm lie, and along the sides of the stream there are extensive marshes. It is the custom to burn out these marshes, which are mostly occupied with palmiet, and the soil that results makes excellent material for a few years, and could be made permanently good if properly treated. These lands lie on what I have taken to be the shale band in the Table Mountain sandstone. Then comes a high ridge of very rugged sandstone hills belonging to the Table Mountain series, and on the north of these there is the main valley. Round the farm itself the whole of the land is levelled, and on the north side it is all still untouched palmiet marsh ground. The hills have been so burnt out and the vegetation destroyed, thereby rendering the springs very weak, that there is not enough water to irrigate the whole of this ground if it were prepared for tilling, and the marsh ground here serves no useful purpose, as it merely conserves the water for the Kouga River, which lies in too deep a hollow ever to be useful for irrigation purposes in the neighbourhood. On either side of the marsh ground the land rises slightly, and levelled flats occur covered with ironstone gravel, supporting a thick growth of heaths and proteas, an original flora which is being invaded by the useless rhenoster bush.

On the north side of the marshes there is another high ridge of sandstone hills, with the beds standing vertical, and on the north of this again a narrow tract of shaly beds, which I should feel inclined to class as belonging to the shale band, on account of its insignificant extent and its lying symmetrically with the one on the south in respect to the main Bokkeveld valley. In the next or fourth valley the beds are dipping at about 70° to the north; between it and the third valley the rocks lie flat. There is a great drop in the river bed here, and the water pours over the krantzes of the Table Mountain sandstone by a waterfall; the valley increases rapidly in depth, and the river, which at the homestead on Twee Rivieren is a sluggish stream, bordered by swamps, becomes a torrent confined between high and vertical walls of quartzite.* There is a small band of slate just below the top quartzites on the north side of the valley, which may possibly be the shale band.

* Compare the description of the Leeuw River in the Cold Bokkeveld in Ceres where the same conditions prevail: Ann. Report for 1900, p. 72.

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The ridge of Table Mountain sandstone here rises precipitously, and is called Hex Hoogte. The valley on the north of this is very narrow, yet the slates are sufficiently distinct to be definitely classed as Bokkeveld; fossils, however, were not obtained. The Table Mountain sandstone is thrown into a series of small folds, the rock as a whole dipping north at a very high angle, and, in fact, to the east it is standing vertical; the crushing makes little knuckles of the sandstone rock appear through the slates, and the structure of the country cannot be put in on small scale maps. The topography is extremely perplexing about here, and the maps are by no means accurate.

To the north of this Bokkeveld inlier there is a heavy tract of Table Mountain sandstone, called the Oude Berg. A splendid section of the rocks is afforded along the Kouga River, which cuts clean across it in a gorge so precipitous that the age of it cannot be very great. The rocks at the south end are extremely contorted, and the beds in the axes of the synclines and anticlines are not in contact, so that caverns are formed; they are unapproachable, as the cliffs are vertical and the Kouga River forms one long deep pool about here. On the north of the Oude Berg there is the valley of the Kouga, which will be described separately.

The hills on the south of the main valleys in the Long Kloof are called the Long Kloof Mountains; they form a continuation of the Outeniquas and the Langebergen, but are separated from the former by the strip of Bokkeveld beds that runs down past Edmonton or De Vlugt. The strata dip south at from 60°-80°, and the long ridge of crests lies in an area which is probably bent into an S-shaped fold, that is, an anticline and syncline closely pressed together and obscuring the details of the folds. The highest point is Krakeel River Peak, 5,500 feet.* The trend is 15° south of east. On the north of the main line of peaks there is a tract with deep side kloofs running parallel to the general trend of the mountains; in the neks between any two adjacent kloofs there is exposed an exceedingly sharp anticline, the various beds on either limb meeting at an angle with scarcely any rounding, the southern limb dips 60° south and the northern 80° north. Between this tract and the first recognisable slate valley there are two more of these longitudinal valleys, occupied by streams running into the transverse or main streams in directions 15° south of east and 15° north of west respectively; the southern of the two represents the valley of a syncline, the beds being nearly vertical, but inclined altogether at about 20° to each other, that is to say, the two limbs dip 80° north and 80° south. In the second of the two the beds are actually vertical, and I think there is a compressed anticline along here.

* Sir D. Gill, Geodetic Survey of S. Africa, 1901, p. 181.

There is a little wood in the kloofs, but this is being rapidly cut out; on the south of the mountains, on the other hand, there are abundant forests. There is an immense drop on the south side, and the erosion is consequently much more vigorous, so that the tendency is for the coastal streams to capture the waters of the Long Kloof, as has actually happened in the case of the Keurboom's River.

THE KOUGA.

Between Avontuur and Uniondale there is an exceedingly steep mountain pass, and at the same time the river that comes down from Prince Albert's Pass to the south of Avontuur has cut a deep narrow gorge through the mountain, and joins the Kammanassie River at Uniondale. The curious disposition of the river-drainage about here was referred to in last year's report, p. 117, and what has happened is briefly this:—The Olifant's River, owing to its course lying for a large part in loose Enon gravels, excavated its bed so rapidly that its head streams were enabled to steal part of the water from the Kammanassie River. The latter river then in turn began to eat back into the drainage area of the Kouga River, and the latter at its source is now being invaded by a neighbouring river, whose bed lies 600 feet lower; the consequence of this is that the connecting link between the two systems, that is to say, the stream joining the Kammanassie at Uniondale, comes out of the Long Kloof by a series of waterfalls, and the gorge that it has made is so recent and so narrow that it has been impossible to cut a road alongside it, and therefore the pass has been carried over the top of the hills. Before the Kammanassie tributary had eaten back into the Long Kloof there was a period when the downward erosion of the rivers just inside came to a standstill, and the whole of the country was base-levelled. The stream coming from De Hoop at that time turned round at Avontuur, and the waters found their way into the Kouga River, but owing to the small fall of the latter, the valley was widened and cut to a level flat. We now find the De Hoop stream bordered by those flats, which are covered with gravel and sand, and are occupied by a great number of farms, the deposits laid on the hard Table Mountain quartzite making good arable and garden soil. Although De Hoop lies on the line of the Kouga Bokkeveld valleys, there is no sign of slates along it; it is only upon passing the nek, Narougas, that one sees the true fertile Kouga farms. The De Hoop stream rising at Narougas Nek flows practically due west, and abuts abruptly on a range of hills, in which it has cut a fine amphitheatre, the levelled flat lying at their base; over this piece of low ground the road to Uniondale is carried before the beginning of the ascent to the Pass. Once upon a time this ground must have been occupied by a marsh, but now the Kam-

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manassie tributary has tapped the water, the part lies high and dry, and steep stream courses traverse it. I have laid stress on this De Hoop valley, as it is so clear an illustration of a recent transference of water area from one river system to another, and of the period of rest and base-levelling that goes on previous to the alteration.

After passing Narougas Nek one comes on a narrow strip of Bokkeveld beds wedged in between high and rugged mountains of Table Mountain sandstone: this is the first of the Kouga valleys. The Kouga River runs in among the hills to the south, and nowhere touches the farm lands in the "Kouga." This first valley stretches almost due east for some twenty miles, and includes the farms Eland's Kloof, Eland's Drift, Klein River, Diep Kloof, Sepree River, and Marias Dal. At Eland's Drift, the first big farm on the west, the crest of the Kouga Mountain is very close, and there is a comparative easy footpath over the mountain to Dwaas in the Olifant's River valley, but from here the mountain crest turns to the north-east, and at Sepree River lies some seven miles away from the valley. The streams that come down have all the appearance of developing, or recent water-courses, as the kloofs in which they run are exceedingly precipitous and narrow; it is only where they widen out on the small strip of softer slates that they make a little flat ground on which farms can be planted.

The Bokkeveld beds are intensely crushed and cleared, and sandstone beds occur in them, dipping at various angles, some north, some south, some lying flat; the movement that these beds have been subjected to has been so intense, and at the same time disjointed, that no order can be observed in the resulting flexure of the strata. Some of the beds of sandstone can be recognised as belonging to the second sandstone, but others may even be small anticlines of the underlying Table Mountain sandstone, that have been pinched out and got separated from the main mass. In among the foot-hills of the mountains at Eland's Drift there are soft shale neks that may be included portions of the Bokkeveld beds, but which are more probably the upper shale band in the Table Mountain series.

Beginning at Eland's Drift, to the south of the slates, there is a zone of crushed quartzite that follows the strike of the slate beds, and widens out and becomes a very notable feature in the Kouga district to the eastwards. The rock is crumbled up into a loose breccia, the fragments averaging two to three inches in diameter, sometimes lying free, with earthy red rock-powder between the individual blocks; at other times, but more rarely, the whole has been re-cemented with iron compounds or silica. The friable nature of this crush breccia makes it weather in a way markedly different from the rest of the quartzites of the Table Mountain series, and one is constantly misled as to its nature; it is only when examining the rock close at hand that it can be

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seen not to be the ordinary Enon Conglomerate. At some places the original bedding of the quartzite remains, but mostly the whole block is one continuous mass of crushed material, and weathers, therefore, in rounded forms.

The line of demarcation between the crush breccia and the ordinary quartzite behind its fairly distinct, but the quartzite near the breccia is traversed by more than the usual number of joint-planes, and hence weathers in a rougher and more rugged manner than the quartzites in the main Kouga mountains. The pieces between the joint-planes become harder and whiter than the ordinary sandstone by the re-cementing of the original grains by silica, so that the hills appear made up of white jagged slabs, shaped somewhat after the manner of the sheared Dwyka Conglomerate at Prince Albert, which Professor Green likened to tombstones. No more forbidding landscape can be imagined than these hills, with their scanty vegetation, unless it be the kloof system in the Kouga mountains opposite, that cuts the whole block of quartzites into a labyrinth of naked precipices.

The width of the Bokkeveld slates nowhere exceeds a mile, but in the east it becomes a mere slip, and yet, with the enormously preponderating sandstone formations around, it carries its peculiar vegetation of Karroo bushes right into the heart of the Heide veld that characterises the Table Mountain sandstone. This can be well seen at Sepree River: the most northern of the farmhouses stands on a small hill of slate, with a little strip of garden ground below, on which tobacco grows, and in the lucerne lands of which ostriches thrive, as in the Cango District, while all round rise the immense buttresses of quartzite, with their proteas and heaths and other sour veld vegetation. The slates are only thirty yards across, and a short way to the east pass into an anticline of sandstone, which conceals them till they emerge far to the east at Schrikke River. The disappearance of the Bokkeveld beds beneath the Table Mountain sandstone was referred to and illustrated in last year's Report on the Baviaan's Kloof, p. 128.

Between the Long Kloof and this first basin of the Kouga the Table Mountain sandstone is thrown into two anticlines, of which the brecciated quartzites includes the more northern, and the jagged quartzites behind the southern. To the west this fold is not apparent, as both limbs dip equally to the south at angles varying about 60°; the Kouga River roughly occupies the axes of the anticline. At Wilde Paarde Pad the river takes an abrupt turn, and flows some two miles to the north, then turns round and after a while occupies its old place in the axis of the anticline; about here, however, the central portion of the fold becomes drawn out and the strata lie flat, while the northern limb dips normally to the north; this is in accordance with the whole trend of the folds about here, which are drawn

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out transversely to make up for the great lateral extent of the mountains.

The sides of the Kouga River are 400 feet high, and are perfectly perpendicular at Wilde Paarde Pad and beyond, past Marias Dal and T'Gunuqua. At the top of the precipices there is a shelf of flat ground covered with ironstone gravel, marking an original base-levelling, and it is possible that formerly the river made a larger sweep to the north than it now does, as the brecciated quartzite from Diepte van Ellende to Sepree River shows a marked hollow, as if it once had been traversed by a large river bed; this, too, would be in accordance with what one would naturally expect, as in a time of less erosion the river would tend to wind about, and not take the uncompromisingly straight course that it now does.

At the farms Sepree River and Marias Dal the brecciated quartzite is cut into by the largest of the Kouga side-streams, the Sepree River or Kouga Bronnen, and the scenery produced is exactly the same in kind as that at Coetzee's Poort in Oudtshoorn, where the side streams from the Zwartebergen have cut steep kloofs in the Enon Conglomerate. In the Kouga, however, the mass of the breccia is greater than that of the conglomerate, and the weirdness of the fantastic weathering enormously increased. The lower farmhouses on these two farms are situated on the breccia, which crumbles and disintegrates not only like the Enon Conglomerate, but the resulting soil seems to be of the same quality. There is an immense krantz of great Table Mountain sandstone boulders cemented with iron compounds on the north bank of the Kouga River, and opposite the lower homestead on Sepree River; it lies some 150 feet above the level of the river.

The access to the farms Sepree River and Marias Dal is down a side stream of the Kouga River that comes from Klein River (Long Kloof), and from its debouchment, along the bed of the main river. The latter is occupied by great accumulations of rounded quartzite boulders and palmiet swamps; when in flood the river runs full between the two banks, and, as I have said before, these banks rise sheer for 400 feet without a ledge, and are made of intensely hard quartzite, stained dark red with iron.

The country to the east of the homestead on Marias Dal is a succession of ridges of Table Mountain sandstone, stretching from the southern of the Kouga ranges to the Kouga River, which cuts them off in the south; they are separated by very steep side streams, and conform to a rough bevel or flat that rises to the mountains; this strip of country is exceedingly wild, and is only used as hunting ground; the strip of crushed breccia passes through it trending due east, but the Kouga River has not taken advantage of it, as we would expect, as it is soft when compared with the compact quartzites.

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The next two basins to the east lie parallel with one another, and are separated by a single fold of Table Mountain sandstone. They likewise strike due east, in contrast with the Long Kloof valleys about here, which have a strong south-easterly trend. The Kouga River touches one end of the valley at Brand Hoek, but immediately plunges through the high complex of hills known as the Oude Berg. In the Brand Hoek basin there are both Enon Conglomerate and brecciated quartzite, the latter lying in the same strike as the mass of it we saw on Eland's Drift and Diep Kloof, and the anticlinal nature of it is here better exhibited owing to its having Bokkeveld beds on either side; the dip of the strata in both limbs, however, is north.

The Braam River strip of Bokkeveld is very narrow, and part of it lies on the high level shelf that is cut here on the south of the mountains, the rock is covered with the ironstone gravel that is so peculiarly characteristic of the flats of the Swellendam Ruggens, and like them is covered with the rhenoster bush.. It is a remarkable fact that in the night the air on this narrow strip of slate in between the sandstones of the Table Mountain series should be warmer than that on the sandstone, though both rocks are cut to precisely the same level. The same phenomenon was referred to in the 1902 Report, p. 15, where the warm air was found in Griqualand East on the strips of red soil resulting from the decomposition of the dolerite dykes that traversed the Molteno beds, the character of the Molteno sandstones being very similar to that of the Table Mountain sandstone. In the Matatiele Report I explained the fact by supposing that greater evaporation took place in the more sandy soil, so that the warmth of the day was rapidly dissipated by the latent heat absorbed in transforming water into vapour, whereas the transpiration on the clayey soil being very slight, the heat absorbed during the day would be returned to the air in the night-time, without being robbed of its heat through evaporation; I think the same explanation will hold good in the case of the strip of Bokkeveld beds in the Table Mountain sandstone.

At the homesteads on Braam River the streams coming from the mountains have excavated a small hollow, in which the farm lands lie. The narrowness and depth of the gorge of these small streams in the sandstone before it enters the slate area is hardly surpassed by the key-hole gorges of Baviaan's Kloof. Braam River is a very old farm, and is celebrated for its orange trees: the soil is very fertile and water plentiful, and the valley entirely sheltered from winds and frost. The orange trees have grown to a size that cannot be beaten in the Colony, the crop from one tree running to 15,000, and that from the tangerine trees to 25,000; the place, however, is so inaccessible that the fruit cannot be taken to market, except in small quantities. I did not follow this valley to the east, as it runs into the Humansdorp

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Division, and it will, therefore, be investigated more closely when that part of the country is surveyed.

The Brand Hoek-Opkomst valley is likewise a narrow strip of Bokkeveld slates in among the Table Mountain sandstone, but it is broader, averaging about a mile in breadth, and the Kouga River crossing it at one end has laid out a fairly wide plain, on which many farms lie. There has been much movement in the slate band, and a mass of Enon Conglomerate has been let down by folding and faulting. One little patch lies against the fault-face that forms the south bank of the Kouga River for a short distance about here, while the main occurrence lies on a dip-slope of Table Mountain sandstone, and in part of Bokkeveld beds, on the north, and is faulted down on the south side against a bed of sandstone that probably belongs to the Bokkeveld beds; at any rate, on the south there are the Table Mountain sandstone hills, then a strip of Bokkeveld slates, and then this bed of sandstone; the last is only some three feet thick, and stands vertical, and the jointing has cut it into blocks for all the world like masonry work. I could not find out the exact shape of this basin of Enon conglomerate, as its top is cut flat with the Bokkeveld beds in the east, and the two formations covered with gravel belonging to a much more recent age. It does not cross the stream by Braam River, so that the whole outcrop would be about two miles long by a mile broad, and the ends are probably rounded like in the Enon Conglomerate basin at Swellendam or in Baviaan's Kloof. The circular folds and faults by which these rounded masses of conglomerate are let into the solid geology of the country, as if fitted like a carpenter would fit a piece of one kind of wood into another kind, is referred to and illustrated in last year's Report on Baviaan's Kloof, pp. 119-135, and is as remarkable an instance of crustal movements by which the rocks of the earth's outer envelope are twisted and transported from their original positions of deposition, as can be found in any part of the world.

The eastern end of the Opkomst basin becomes very wild, the Kouga tributaries have cut narrow gorges through the soft slates four to five hundred feet deep, and the sides of the hills are very steep; on top are the ordinary high-level gravels. Beyond Opkomst the Humansdorp Division begins, and there are probably more of the Enon basins in that area connected with the great mass of Uitenhage series that occurs along the Gamtoos River, or, at any rate, formerly connected with this before the later post-Uitenhage movements cut the great superficial extension of these beds into a number of isolated areas.

Following the Opkomst streams downwards one passes through a great mass of Table Mountain sandstone hills, planed down to a common level and covered with high-level gravels; then on nearing the Kouga River there is another area of Bokkeveld slates. In the centre of the softer beds there is an anticline

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of Table Mountain sandstone which the Kouga River has chosen to excavate its bed in, rather than wear away the slates which are far more liable to disintegrate on exposure. This anticline is closely folded together, and dips in both its limbs at about 15° south, and the more northern of the bands of Bokkeveld beds becomes caught in a syncline that rises towards the east, and as it does so becomes narrower, so that over the Humansdorp border it probably pinches out. There are no farms on this Bokkeveld area in the Uniondale Division, as the kloofs are too narrow and deep, and all the available water for irrigation purposes is absorbed by the farms nearer the mountains, but a little arable land has been made on the tops of the flat-cut hills that border the Kouga River on the south side, the red ferruginous soil being fertile when moderately supplied with rain-water; the soil on the hill-tops is as a rule kept more damp than in less exposed areas, the reason probably being that the vegetation is able to absorb moisture from the passing cloud-mists without these turning to rain, and thus supplying the whole surface of the land, hill and valley alike, with water.

In among the Kouga mountains there is yet another band of Bokkeveld beds. It is too narrow to make any great feature in the topography; nevertheless, the river where it cuts across it makes a small basin, which could be utilised for farm lands. The beds are wedged in vertically in the sandstone, and though the whole outcrop is only some hundred yards wide, the whole set of beds have been crushed together and multiplied three times, the fold taking on the shape of an **N**. The crest of the anticline divides the shales into two portions, so that when looking over the mountain country one can see the slate band running east and west across the direction of the streams, and forming low neks in the long foot hills, each of these neks being divided in two.

It is, of course, possible that these slates belong to the shale band in the top series of beds in the Table Mountain sandstone. A little north of this there are massive calcareous slates interbedded in the sandstones; there are three or four beds separated by sandstone, and the whole thickness is about 40 feet; these I take to represent what remains of the shale band after being subjected to the intense pressure that the rocks have undergone. Taking the section of the Kouga mountains at Schrikke River, the width of the area of Table Mountain sandstone outcrop between this shale band and that on the flats on Beako's Nek in Baviaan's Kloof, we get a distance of six miles, or taking the thicker slate band just described as Bokkeveld beds, the whole superficial extent of the series would be seven miles. I could only see one great anticline in the mass, and that was high up near the crest of the mountains overlooking Baviaan's Kloof. There are many of minor folds in the area about the zone of the

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Fig. 1.—View of the Kouga Mountains, looking north across the narrow valley of Bokkeveld Beds. On the right is shown the N-shaped fold in these beds. The high peak on the right is the Kouga Berg, rising to nearly 7,000 ft.

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Fig. 2.—View of the Kouga Mountains, looking west, across the valley of the Schrikke River. The small river in the foreground is cut along the narrow inlier of Bokkeveld Beds. The double nek formed by the softer slate beds is shown on the sky line at N. N. The course of the Schrikke River is shown by the arrow. On the left there is the sharp bend in the Table Mountain Sandstone, which lets down the overlying Bokkeveld Beds.

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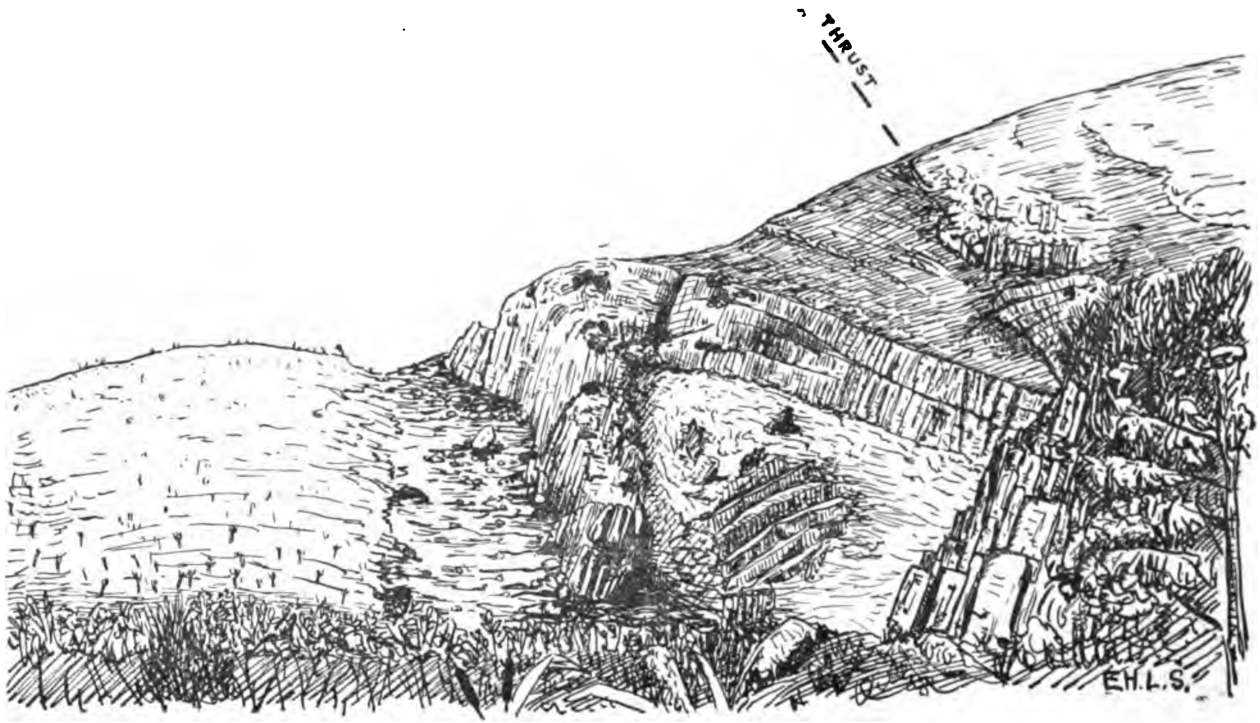

Fig. 3.—Another view of the Schrikke River Syncline, southern side. The sharply folded Table Mountain Sandstone is shown on the right; the hill on the left is made of the overlying Bokkeveld Beds.

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N-shaped folds in the band of Bokkeveld beds, but these are not of very great importance in extending the outcrop of the Table Mountain series, though, of course, they do so to some degree. The dip of the beds varies from 15° to 30° through the greater part of the Kouga mountains, and supposing that the Table Mountain series is 5,000 feet thick, as we have estimated it to be in Worcester and elsewhere where it is normally developed, I had expected that the underlying Malmesbury beds would appear in the central axis of the great anticline at the bottom of the kloof that cleaves through the whole mountain mass at Schrikke River. I was unable to find the Malmesbury beds, and this is in accordance with what Mr. Rogers and myself found in the Cederbergen, where similar deep kloofs occur, and where one would expect the rivers, somewhere at least, to have reached the rocks underlying the Table Mountain beds. It seems remarkable that in two districts widely apart the rivers should have just reached a point in their downward sawing through the Table Mountain sandstone which nearly, but not quite, reaches the underlying beds; the fact shows that there must be two constant factors to be reckoned with: the rate of erosion and the height of the mountains above sea-level. The first depends on the grade of the rivers and the amount of precipitation, which can very well have been equal in the two districts, but the second depends on the question whether a rock, such as the Table Mountain sandstone, can be pushed up above the sea-level to an indefinite height, or whether the limit is reached when the strength of the rock is insufficient to bear a weight of more than a certain amount of its own material. Supposing this latter to be the fact, then we must suppose the crushing forces to have acted on the Table Mountain sandstone in the Cederbergen and the Kouga mountains, and to have pushed the series upwards till it reached the limit, every additional thrust that tended to lift the rock higher than this limit would be neutralised by the rock beneath the mountains being unable to bear the strain and crushing or flowing under the pressure. In this way the two sets of mountains with different amounts of tangential thrust would both reach the same sky-line owing to their similarity of composition, while the difference in amount of the thrust would result in the more complex folding of the rocks extended laterally around them. From a comparison of the geology of the country adjacent to the Cederbergen and the Kouga mountains it is very evident that an enormously greater amount of folding has gone on in the Kouga district than in the other, and that the mountains have not reached a greater vertical development must, I think, depend on some such explanation as I have put forward.

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THE GEOLOGICAL SURVEY

OF THE

DIVISIONS OF ALIWAL NORTH, HERSCHEL, BARKLEY EAST, AND PART OF WODEHOUSE

BY

ALEX. L. DU TOIT.

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GEOLOGICAL SURVEY

OF THE

DIVISIONS OF ALIWAL NORTH, HERSCHEL, BARKLY EAST, AND PART OF WODEHOUSE.

BY ALEX. L. DU TOIT.

The area examined includes the whole of the divisions of Barkly East and Herschel, almost the entire division of Aliwal North, and about half of Wodehouse, namely, all the ground lying to the north-east of a line drawn from Xalanga Peak to Dordrecht, and thence to Jamestown. A visit was paid to Moyena, in the Quthing Division of Basutoland, and a few of the notes made have been incorporated in this report.

On the north the area is bounded by the Orange River, which flows in a winding channel at a depth of several hundred feet below the general surface of the country. On the north-east the boundary is formed by the Telle River from Palmietfontein to a point a little east of Lundean's Nek; thereafter along the crest of the Witteberg Range to Tina Head on the escarpment of the Drakensberg. There exists still unsettled a dispute between the Basuto chiefs and the Colonial Government as to the precise boundary line near Lundean's Nek. This corner of the Herschel Division has not been included in the divisional map, and consequently was not geologically surveyed. On the east the escarpment of the Drakensberg forms an almost unbroken wall for many miles, separating Barkly East from Mount Fletcher and Maclear. The mountain range rises to close upon, or exceeds, 8,000 feet above sea-level, and the sky-line is only occasionally indented. Through these notches bridle-paths run, and are, beginning from the north, Lehana's Pass (up which a road is now being cut), Tsitsa Pass, Pondo Pass, Burgher's Nek, and Tembu Pass, the second being the route most frequently travelled.

On the south the boundary is the Drakensberg again (described already in the account of the geology of Elliot),* and the watershed running from Xalanga Peak to near Dordrecht. The limit on the west has already been noted, the only portion of Aliwal North yet remaining unsurveyed being the high ground known

* Ann. Rept. Geol. Com. for 1903, p. 169.

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as the Stormbergen on the west of the division. The country is extremely diversified; a flattish tract occurs in Aliwal North along the Kraai River, in altitude from 4,200 to 4,800 feet above sea-level, but in Wodehouse the surface is deeply intersected with rivers. In Herschel the centre and south are very mountainous, while the division of Barkly East is a great plateau deeply carved into by denudation. The Kraai River valley has an altitude of about 6,000 feet above sea-level, the rivers flowing in narrow winding channels, often of considerable depth. The altitude of the town of Barkly East is 5,960 feet, as determined in the course of the railway survey. Towards the south the Drakensberg rises to an altitude of from 7,000 to 8,000 feet, but the highest part of the country is formed by the Witteberg Range, which separates Herschel from Barkly East and part of Aliwal North. Two of the highest peaks, Snowdon and Avoca, were measured with theodolite from Barkly, and proved to be 9,150 feet and 9,160 feet respectively. Several other peaks farther east along the range, Baldock, Hawkshead, and Benmacdhui, are about the same in height, while the highest point is said to be Tina Head, at the junction of the Witteberg Range with the Drakensberg. The only gap along this lofty ridge is the narrow pass known as Lundean's Nek, leading over from Moshesh's Ford in Barkly East into the valley of the Telle River.

The whole of the area dealt with in this report is grass-covered, and as a consequence sheep farming is an important industry, but years back there must have been parts which were very well wooded. I was informed by Mr. O. Brigg, of Maudesley, near Lady Grey, that thirty years ago the kloofs along the Orange River were filled with abundant vegetation, and large olive trees were numerous.

The trees were cut down by the natives and the timber taken to Aliwal North, so that at the present day only small shrubs remain in their place.

Manure is now largely used as fuel; this, and the practice of burning the grass, is having a very injurious effect upon the veld. Near the village of Herschel great dongas or ditches have been formed on the flats, some of which run for miles, and are of considerable depth. All have been formed within very recent times, and the rate of excavation is on the increase. Not only is the rich soil being carried away, but the dongas act as drains in removing moisture from the ground, and as a natural result we have the failure of the crops, except when the season's rainfall has been unusually abundant. In Aliwal North the soil is rather poor as a rule, owing to the wide outcrop of the gritty sandstones of the Molteno beds. In Barkly, on the other hand, the soil is generally rich, owing to the disintegration of the Volcanic beds; the material derived from the crumbling of the Cave sandstone, however, does not, as a rule, support any but a scanty vegetation.

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The rocks which cover this area consist almost entirely of the various members of the Stormberg series, but in the north-east corner of Aliwal North there is a small tract occupied by beds belonging to the upper part of the Beaufort series, or, as they have been designated in this report, the BURGHERSDORP BEDS. Penetrating the sedimentary and volcanic beds are, firstly, a large number of volcanic necks, and, secondly, a later set of intrusions, the Karroo dolerites, in the form of dykes and sheets.

The order of succession of the beds from above downwards is as follows:—

Stormberg series	Volcanic beds	Compact and vesicular lavas, volcanic ash, and thin beds of white sandstone.
	Cave sandstone	
	Red beds	
	Molteno beds	
Beaufort series.	Burghersdorp beds.	

The characteristics of all these different divisions, except the last, have been so often described elsewhere† that it is unnecessary to do more than briefly note their most important characters.

The Burghersdorp beds contain soft whitish or greenish fine-grained sandstones, with beds of red and purple shales, mudstones, and clays; reptilian remains are common, but those of plants infrequent.

The Molteno beds do not, as a rule, contain any bright-coloured rocks, but gritty sandstones and pebbly grits are of frequent occurrence. While plant remains are abundant, those of reptiles are practically absent.

In the Red beds we have a return to the same conditions under which the Burghersdorp beds were deposited, and reptilian remains are not uncommon.

The Cave sandstone is a group of yellow to white sandstones of considerable thickness; in it bones are occasionally found. Plants are almost entirely absent from these uppermost two members of the Stormberg series. The Volcanic beds must have been of great thickness originally, and now form all the higher ground in the area to be described.

In the following report the Molteno beds will be described separately for each Division in which they occur, and the same plan will be followed with regard to the Red beds. The Cave sandstone and Volcanic beds will be described together, and as the area in which they occur is not too large, the account will not be separated according to fiscal divisions.

† See reports by Dunn, Green, North, Molyneux, etc.; also Ann. Reports of Geol. Commission for 1902 and 1903.

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The geological structure of the district is simple. The beds lie either horizontally or are inclined at small angles. At three places monoclinal folds were seen to occur. The strata have been affected by two sets of folds, neither of them of any great intensity, one set striking a few degrees east of north, and the other set varying in direction from ten to thirty degrees north of east. As will be seen from the map (fig. 1), the folds of the second set are somewhat curved. Probably it will be found that as they are followed westwards their direction will come finally to coincide with the east and west folds of the southern part of the Colony. Towards the east and north-east they will probably

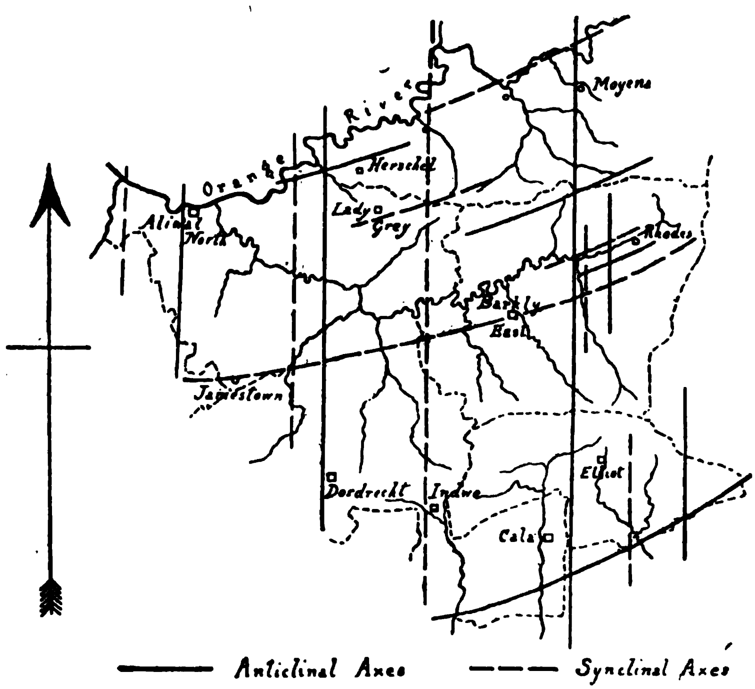

Fig. 1.—Map of area surveyed showing axes of foldings.

be found to bend more and more towards the north, tending to parallelism, with the folds affecting the beds in Pondoland and Natal.

It is important to note that both the Kraai and Orange Rivers in the upper parts of their courses run parallel to these folds; the reason for this will be discussed later. The dips produced by the folds seldom exceed five degrees, but, if as sometimes happens, the dip continues for thirty or forty miles, there will be a displacement of any one bed through thousands of feet. In addition to the folds marked in on the map, there are numerous

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small irregularities, due chiefly to the tilting of the strata in the neighbourhood of volcanic necks. In at least two areas subsidence has taken place during the period of volcanic activity.

Volcanic necks are numerous in the area examined, while dolerite dykes and sheets are abundant. The dolerites, however, are not of the same importance or on the same scale as the intrusions of the Karroo or the Transkei.

II. THE BURGHERSDORP BEDS.

In the extreme north-east of the division of Aliwal North there occur certain rocks which in the course of mapping have been separated from the overlying strata. It was at first uncertain whether these lower beds should not be regarded as the downward extension of the Molteno beds, but it was afterwards decided to group these beds in the Beaufort rather than in the Stormberg series.

As it is well known that the Beaufort series includes a vast thickness of sediments, it has been thought advisable to adopt a local name for their uppermost portion, which has characters enabling it to be recognised at points as far removed as Steynsburg, Queenstown, and Xalanga. From their typical development around Burghersdorp these beds have been named the BURGHERSDORP BEDS.

The fauna of the lower portion of the Beaufort series is entirely different from that of the Burghersdorp beds. The former is characterised by reptilia such as *Pareiasaurus*, *Oudenodon*, and *Titanosuchus*, the latter by reptilia belonging to the order theriodontia, while in addition the remains of amphibia are not uncommon. The adoption of the new name BURGHERSDORP BEDS is thus justified.

In Aliwal North these beds occupy a comparatively small area, chiefly between the lower part of the Kraai River and the Kraamberg and between the latter and the Stormberg spruit. A small thickness, not more than 400 feet of strata, are exposed. The Burghersdorp beds, however, cover a large area in Albert and Steynsburg, and their outcrop bends round through Queenstown, Glen Grey, into the Transkei; in Xalanga† they were termed "Beaufort beds," as so little was then known about their fossil contents.

The Burghersdorp beds are characterised by beds of yellow to buff fine-grained sandstones associated with purple, red, and grey sandstones, shales, mudstones, and clays. The sandstones are spaced rather farther apart than in the Molteno beds, and seldom give rise to any well-defined ridges. Pale bluish hard sandstone occurs occasionally, for example, along the bank of the Orange River at the Aliwal North waterworks, but this may

† Ann. Report Geol. Commission for 1903, p. 173.

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perhaps only be the unweathered form of the softer yellow sandstone. Clay-pellet conglomerate is fairly abundant, and occurs along with ferruginous lenticles of coarse gritty sandstone and fragments of leaves and stems of plants. The purple sandstones are soft and often well-bedded; at a point close to the railway station the rock is quarried for use as paving slabs.

The argillaceous rocks are usually red and purple in colour, but green tints are not uncommon or the beds are variegated and blotchy. Occasionally these softer beds exhibit an eroded upper surface, the hollows being filled in with the overlying sandstone. Calcareous concretions and peculiar purple shale- or clay-pellet conglomerate occur, and may include fragments of bone.

Some of the beds contain a large amount of iron, which tends to become concentrated on weathered surfaces of sandstone and mudstone, so that the veld is often covered with black shiny pebbles and boulders. Some of the iron must have originally been in the form of sulphide, for nodules and lenticles of iron pyrites occur in a yellowish sandstone on the Jamestown road, about six miles south of Aliwal.

The Burghersdorp beds form the flat ground south-east of Aliwal almost up to the base of the Kraamberg. The boundary with the Molteno beds is irregular in plan, due partly to the contour of the ground and partly to the drop produced in the beds by a monoclinal fold running a little west of north from Olyve Fontein to Oranje Fontein. The purple-red rocks extend up the Eland's Laagte Spruit as far as Olyve Kloof, with the Molteno beds forming the high ground on the north-west and south-east. Up the Kraai River the Burghersdorp beds extend as far as Plaat Kop, and then dip beneath the Molteno beds at a low angle.

About five miles south-east of Aliwal there is a long ridge running nearly north-eastwards, and cut through both by the Kraai and the Orange Rivers. This ridge is due to a great dyke of dolerite which dips to the north-west, and which has partly protected the strata on either side from denudation.

Hence there is left a great mass of Molteno beds; had denudation been a little more rapid, the thin capping of rock overlying the Burghersdorp beds between the Kraai and Orange Rivers (on Zonnebloem) would have been cut through with the production of an outlier of Molteno beds.

For many years now the town of Aliwal North has been noted for its hot springs. These occur a little south of the town in a peaty flat, underlain by Burghersdorp beds.

There are two springs, each about twenty feet in diameter and about eighty feet apart, surrounded by a growth of vegetable material approaching peat very closely in character, and which has to a small extent been utilised for burning.

The nearest outcrops of rock are sandstones, shales, and mudstones, while about 100 yards below the springs a small dolerite

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dyke crosses the shallow depression in which they are situated. There is thus nothing to indicate any reason for the presence of the outflow precisely at this point.

According to Mr. Alfred Brown, of Aliwal North, the springs were quite insignificant some seventy years back, when Aliwal was founded. By opening up the ground the volume discharged was much increased, and in June, 1904, when I gauged the springs I found the outflow to be between 650,000 and 700,000 gallons per diem.

It is not certain whether the two springs are very closely connected; at the time of my visit one of them was perfectly clear, while the other was very turbid, a rather unusual phenomenon. Attempts have been made to prove the depths of the fissures, but the results show that the rock walls descend vertically to an unknown depth.

The following is an analysis of the water by Dr. Hahn:—

Carbonate of lime...	7·41	grains per gallon.
Sulphate of magnesia	1·95	" " "
Sulphate of alumina	3·24	" " "
Sulphate of potash	·95	" " "
Chloride of calcium	8·10	" " "
Chloride of sodium	61·35	" " "
Silica...	1·04	" " "
Carbonic acid gas...	5·22	" " "
Organic matter	*trace.*	

I noticed, too, the presence of a small quantity of sulphuretted hydrogen, and Professor Pearson informs me that the brownish flocculent material which collects round the sides of the springs is due to a sulphur bacterium.

Fossils are fairly abundant in the Burghersdorp beds, and considerable collections have been obtained by Dr. Kannemeyer from around Burghersdorp, and by Mr. Alfred Brown from around Aliwal North, while a number of specimens have been recorded from Smithfield and Rouxville, in the Orange River Colony, where these beds cover a considerable area.

The plant remains are confined almost entirely to the beds of yellow sandstone or very arenaceous shale, and are never in a good state of preservation, so that it is impossible to determine the exact species in most cases. Hitherto no plant remains from these beds have been described anywhere. The following were obtained at the Kraai River Bridge, six miles south-east of Aliwal, and just below the base of the Molteno beds:—*Thinnfeldia*, *Callipteridium*, *Taeniopteris*, and *Pterophyllum*. The last named is a genus not hitherto recorded from the Cape Colony, though I have found one species in Elliot along with *Thinnfeldia*, while another species has been obtained by Mr. Anderson in Natal† similarly associated. The *Pterophyllum*

† Second Report of the Geological Survey of Natal and Zululand, p. 102, 1904.

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from Aliwal shows the venation very clearly, and resembles the species *P. jaegeri* from the Keuper (Upper Trias) of Germany.

From the ridge overlooking the town of Aliwal were obtained several fronds of *Glossopteris* and some striated and pitted stems. Mr. Brown's collection from the same bed includes a narrower frond of *Glossopteris*, a large species of *Pterophyllum*, a large leaf apparently of a *Ginko*, *Thinnfeldia*, and a very large frond of a plant resembling *Callipteridium* in habit, but differing from it in several important particulars.

Of great importance, too, are the number of seeds and *Lepidodendroid* stems which Mr. Brown has discovered in the Burghersdorp beds.

From a slightly lower horizon on the north bank of the Orange River, opposite the town, I obtained a large strobilus, some seeds, and a leaf sheath and striated jointed stems, probably belonging to a species of *Schizoneura*.

Reptilian remains are of frequent occurrence in the Burghersdorp beds, being commonly embedded in the soft red and purple shales and mudstones. Many of the forms have been described from time to time by Owen, Huxley, Seeley, and Broom.

Among the reptilia the following have been obtained from the Burghersdorp beds of the Aliwal North division:—A dinosaurian *Euskelesaurus brownii* (?) (Seeley)* from Oorlog's Fontein, near the Kraai River. From a bed about six feet above the spot where Professor Seeley obtained the jaw he describes, Mr. Brown removed some bones, which he presented to the Museum this year. The remains include the scapula, coracoid, humerus, radius and ulna, part of the pelvis, several vertebrae, a few ribs, and some of the digits, but the animal has not yet been identified. On the same farm I found a portion of the ramus of a jaw, but too fragmentary to be capable of determination.

From the farm Melk Spruit, a few miles west of Aliwal, Mr. Brown obtained a number of fossils, which were determined by Professor Seeley† as belonging to the Theriodontia. They are:—

Microgomphodon oligocynus,
Trirachodon kannemeyeri (?),
Diademodon mastacus,
Diademodon browni,

and a tooth of *Cynognathus berryi*.

Remains of amphibia also occur in the Burghersdorp beds.

From the ridge just above the town of Aliwal Mr. Brown obtained a portion of a very peculiar stegocephalian, named by Dr. Broom†† *Batracosuchus brownii* (Broom). From a hard fer-

* Ann. Mag. Nat. Hist. Ser. 6, p. 335, Vol. XIV., 1894. Dr. Broom believes there is some mistake in the identification.
† Trans. Phil. Soc., London. Vol. 186, Pt. IX., Sects. 3 and 4.
†† Broom. Geol. Mag., Ser. IV., Vol. X., No. 11, p. 499.

ruginous clay-pellet conglomerate bed Mr. Brown obtained sculptured plates of a second stegocephalian, named by Dr. Broom‡ *Cyclotosaurus albertyni* (Broom). This labyrinthodont is almost identical with the species *C. robustus* from the middle Keuper (Upper Trias) of Würtemburg, Germany. On the Aliwal commonage there was also found a portion of the jaw of a small mammal, called by Dr. Broom** *Karroomys brownii* (Broom).

No fishes have been obtained in Aliwal North, but in the same beds at Burghersdorp, Smithfield, and Rouxville there have been found *Semionotus capensis*, *Cleithrolepis extoni*, and *Ceratodus capensis*.

A review of the fossil flora shows that *Thinnfeldia* occurs in the uppermost portion of the Burghersdorp beds, both in Aliwal and Xalanga,‡‡ associated with forms apparently identical with *Taeniopteris*, *Callipteridium*, and *Stenopteris*, evidently a typical Molteno flora, but in addition we have also *Glossopteris* and *Lepidodendroid* stems, neither of which have up to the present been found to occur in the Molteno (coal-bearing) beds of the Colony.

The presence of the abundant reptilian and amphibian fauna influences one in making a division here, and using the vertebrates instead of the plants for the purpose of zoning the Karroo beds.

There is a marked lithological difference between the Burghersdorp and the Molteno beds. Red and purple are the predominating tints of the softer rocks in the lower formation, and there are never any carbonaceous beds. Consequently it has been thought necessary to draw the dividing line at the summit of these bright-coloured rocks and place them in the Beaufort series. It must be admitted that to our present knowledge this boundary line is not coincident with one and the same stratigraphical horizon throughout, as the colouring occasionally rises very close to that important geological bench mark, the "Indwe sandstone," while at other places it is very much below it.

This may, however, be due partly to irregularity in deposition and partly to differences in constitution of the original sediment.

The age of the Burghersdorp beds is proved by the fossils they contain. The presence of the labyrinthodonts and fishes indicates that the formation is homotaxial with the Keuper (Upper Trias) of Europe. The Burghersdorp beds may also be considered to be equivalent to the Hawkesbury series of New South Wales, which also contains labyrinthodont remains and

‡ Broom. Rec. Albany Museum. Vol. I., No. 3, p. 178. 1904.
** Broom. Geol Mag., Ser. IV., Vol. X., No. 8, p. 345. 1903.
‡‡ Ann. Rep. Geol. Com. for 1903, p. 175, footnote.

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fishes of not only the same genera, but of closely allied species. The age of the Australian formation is now well established as being Upper Triassic.[*]

Thinnfeldia odontopteroides and *Stenopteris elongata* both occur in the Hawkesbury series, but not *Glossopteris* or *Lepidodendroid stems.*

In the Rhaetic beds of Tonkin we may note that *Glossopteris* occurs along with *Taeniopteris.* In India we find the Pánchet formation, with a fauna and flora remarkably like that of the Burghersdorp beds, *e.g.*, dicynodonts, and labyrinthodonts, *Thinnfeldia* and *Glossopteris.*

The presence of lepidodendroid stems in the Burghersdorp beds is interesting as showing we have here surviving one of the typical palæozoic types.

The evidence of the plants of the Molteno beds points to their being of Rhaetic age,[†] which thus confirms the view that the Burghersdorp beds are Upper Triassic. The Molteno beds may thus be the equivalent of the Wianamatta series of New South Wales.

III. The Molteno Beds.

(i) *In Wodehouse.*

Around Dordrecht there is a considerable area of Molteno beds, and the same formation extends towards the south and south-east, and again to the south-west along the Sterkstroom-Indwe railway.

The surface of the country is not very hilly; kopjes and ridges are produced by the weathering of dolerite intrusions, while now and again there occurs an outlier of Red beds. North of Dordrecht the Molteno beds crop out only over the low-lying ground, in the valley of the Holle Spruit as far as Flaauw Kraal and for some distance down the gorge of the Wolve Spruit. The remainder of the north-eastern half of Wodehouse is built up of Red beds, with Cave sandstone and Volcanic rocks.

The country intervening between Indwe and Dordrecht was mapped by E. J. Dunn in 1878, but I have not yet been able to go over it, consequently there remains undecided the exact geological horizon of the coals at Dordrecht.

The chief geological interest centres around Dordrecht; further to the north only the uppermost beds of the Molteno group occur, and fossils are infrequent.

The outcrops are usually fine-grained, grey felspathic sandstone and occasionally coarse "glittering" sandstones, with blue and yellow sandstones, shales, and mudstones.

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* A. Smith-Woodward. The Fossil Fishes of the Hawkesbury Series at Gosford. Mem. Geol. Survey, N.S.W. Palæontology, No. 4, p. 55, 1890.

† Seward. Fossil Floras of Cape Colony. Annals of the S.A. Museum. Vol. V., Pt. I., p. 73, 1903.

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By the weathering of these soft sandstones extensive sandy flats are often formed, for example, at Jackal's Kop, Vlak Fontein, Treur Fontein, and north of Labuschagne's Nek. The sandstones are often extremely coarse-grained, with little pebbles of white vein-quartz; in some places they are conglomeratic, for example, on the farm Vlak Fontein, about 12 miles north-east of Dordrecht.

The beds at Dordrecht were first described by G. W. Stow,* and the section he gives of the hillside, with its capping of columnar intrusive dolerite, overlooking the town on its east side, is quite correct, though at the present time the rocks are not so well exposed.

Silicified wood occurs in the sandstone along the hillside, but none of the larger trunks mentioned by Stow and later observers now remain, the material occurring only in small fragments.

All round about the town wherever this bed of friable sandstone crops out there are found fragments and masses of this silicified coniferous wood. Above this "forest-zone," as Stow has called it, come coarse-grained pebbly grits with beds and lenticles of ironstone conglomerate.

Immediately outside the town, to the north-east, there occur in a small quarry many portions of stems with the woody tissue now entirely replaced by haematite and limonite. In the Transkei a zone of sandstone with fossil wood was found to be a conspicuous member of the Molteno group, and the question naturally arises whether this bed is not on the same geological horizon. I think, however, that it is several hundred feet higher in the formation, and although no such zone was found in Elliot, yet such a one occurs in Aliwal North near the hill called Windvogel Kop, north-east of Jamestown. Both at the latter spot and at Dordrecht the "forest-zone" occurs on a horizon about 400 feet below the base of the Red beds.

Along the ridge just outside the town on the south-east side is an opening, which exposes hard black carbonaceous shale, with thin films of coaly material, on a horizon a little below the "forest-zone."

About 50 yards farther south, and about 12 feet lower down, there is exposed a four-foot carbonaceous shale band, slightly disturbed, and in contact with a dolerite dyke. This dyke, running east and west, occupies a line of fault, and it is impossible to say whether this second exposure of shale belongs to the same bed as the first or whether it is on a slightly lower horizon, for a north and south dyke, occupying a line of fault, has disturbed both beds.

I believe, however, that there are two beds of carbonaceous shale separated by about fifteen feet of soft sandstone. In several of the wells sunk in the town thin coals have been

* Stow, Quart. Journ. Geol. Society. Vol. XXVII., p. 523, 1871.

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struck, associated with black carbonaceous shales; perhaps we have here the horizon of the lower shale band just mentioned.

Nearly a mile farther south between the town and the railway station a bore-hole was put down by the Public Works Department on the right bank of the small spruit (on the farm Drie Fontein). A seam of coal stated to be 2 feet 6 inches in thickness was struck at a depth of 212½ feet, underlain by at least 40 feet of dark shale.

It is interesting to note that Mr. F. North† put down a bore-hole in the flat just below the town, but had to abandon the work after reaching a depth of 164 feet, probably not far above the position of the coal struck on Drie Fontein.

The exact geological horizon of this coal is uncertain, but it certainly lies above the Indwe sandstone and coal.

Dolerite occurs as a thick sheet on the east of Dordrecht, and runs past the railway station across Botha's Hoek, sheets being given off at intervals from the main mass.

It is on account of the presence of these sheets that prospecting is rendered so difficult in this neighbourhood, added to which are the numerous narrow dolerite dykes which traverse the beds.

Galloway in his report†† mentions a peculiar dyke at Dordrecht, in which liquid petroleum escapes from cavities when the rock is freshly fractured. The petroleum has probably been produced by the destructive distillation of the adjacent or underlying seams of coal and bituminous shale by the igneous intrusion.

To the north and north-west of Dordrecht on the Jamestown and Sterkstroom roads there are road quarries in which occur shales and mudstones, with abundant plant remains, *e.g.*:—

Thinnfeldia, odontopteroides, Taeniopteris carruthersi, Callipteridium stormbergense, Stenopteris elongata, Phoenicopsis elongatus, Ginko sp., and peculiar stems.

There is a general dip of the beds away from Dordrecht, which is situated at the centre of a dome; consequently towards the west near Witte Hoogte we come upon the uppermost beds of the Molteno group.

The beds here are affected by a peculiar monoclinal fold just on the watershed between the rivers draining into the Atlantic or into the Indian Ocean. This monoclinal commences at the south beacon of the farm Naauwpoort, and trends about 30 degrees west of north, its angle of dip increasing in this direction.

It forms a fine dip slope of about 40 degrees where the railway has been carried along the face of the incline. It then curves round until its strike is almost due north-east, and finally at the railway cutting on the watershed bends abruptly backwards until its direction is now 10 degrees west of north. From this

† Colonial Mining Engineer's Report on the Stormbergen, p 9, 1878.

†† Report upon the Coal Deposits in the Indwe Basin and Stormberg, p. 9, 1889.

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point it runs straight across country to the west beacon on Moordenaar's Hoek (with a dip of 35 degrees), and must die out in the next few miles, as the strata are quite undisturbed at Oorlog's Poort on the Holle Spruit.

The dip slope is formed of hard fine-grained white sandstone, with thin buff mudstone bands, the former containing a few fragments of *Thinnfeldia* fronds.

The red and purple mudstones of the Red beds are seen on the ridge just west of the railway, so that we are here on the very uppermost portion of the Molteno beds.

The character of this white sandstone and its geological position resembles that of a bed recorded from Ord Fianna in Elliot.*

(ii) *Molteno Beds of Aliwal North.*

In Aliwal North the area occupied by the Burghersdorp beds has already been described; all the remaining low-lying portions of the division, and in addition the Kraamberg in the west, are formed of Molteno beds.

There is a general dip towards the south-east, and judging from the great width of outcrops, there would appear to be a considerable thickness of Molteno beds. This is, however, deceptive, for the Red beds occur crowning the peak known as Kraamberg and the Stormbergen, while not many miles away are seen exposures of the Burghersdorp beds.

The thickness of the Molteno beds is, therefore, at the utmost 1,200 feet, and probably it is nearer 1,000 feet. There is one marked horizon which can be identified over the greater portion of Aliwal North, and that is the horizon of the "Indwe sandstone"†; the higher beds are very much alike, and it was not thought necessary to attempt any smaller sub-divisions.

In the west of Aliwal the railway crosses the end of the long tongue of Molteno beds, forming the Kraamberg. The Indwe sandstone is well seen on Lange Kloof, Oranje Fontein, and Ruigte Fontein, where it forms a krantz about 200 feet above the purple shales and mudstones of the Burghersdorp beds. On Olyve Fontein the valley has been excavated along the axis of a monoclinal fold, and hence the Indwe sandstone behind the homestead is considerably lower in altitude than on the flank of the Kraamberg, while it has a dip of about 15 degrees eastwards. It shows the usual characters; coarse-grained pebbly felspathic sandstones with ironstone-conglomerate beds, while above it come fine-grained sandstones and buff mudstones with shales.

A bed of sandstone with abundant fragments of silicified wood is present on a horizon about 100 feet above the Indwe sandstone, and is succeeded by several bands of black carbonaceous

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* Ann. Rep. Geol. Com. for 1903, p. 183.

† See Ann. Rep. Geol. Com., 1903, p 175.

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shale and impure coal, and then again by soft blue shales and coarse white sandstone.

About a quarter of a mile east of the house, in a little kloof, these beds were pierced by a bore-hole put down by the Public Works Department.

The coal-bearing section is as follows:—

Coal	2 feet	9 inches
Black shale	2 "	0 "
Coal	1 "	9 "
Black shale	1 "	3 "
Coal		3 "
Black shale		9 "
Coal		1 "
Dark blue shale.		

while two other thinner coal seams were passed through at a little greater depth. What is evidently the same horizon was proved on the neighbouring farm, Patrys Fontein, by means of a borehole put down on the hill slope beside the homestead.

Here we get about eight feet of coal and shale mixed, which corresponds to the total in the section on Olyve Fontein.

From their position just above the Indwe sandstone both on Olyve Fontein and Patrys Fontein it is evident that these seams are on the horizon of the Cala Pass and Gubenxa coals. in the Transkei. There is apparently no representative of the Indwe coal here, but thin streaks and lenticles of shiny coal and carbonaceous material occur in the coarse-grained and somewhat false-bedded sandstone. The distance between the Indwe sandstone and the purple clays of the Burghersdorp beds is apparently very small, about 150 feet, but it increases farther towards the east.

On Patrys Fontein coal occurs also on a horizon about 250 feet above the first-mentioned one. One adit has been driven into the hillside just below the great dolerite intrusion of Patrys Fontein and Olyve Fontein, about a mile and a half south-east of the farmhouse. One very hard and thin coal-seam is laid bare in the midst of grey and black mudstones and shales. In the latter are remains of *Thinnfeldia* and *Dichopteris.* About a mile and a half farther north the same horizon has been opened out by means of an adit over 100 yards long. The section shows very regularly bedded mudstones and carbonaceous shales, with a coal seam of about five inches in thickness. Two openings, each a little bit lower than the last, occur close at hand, and show somewhat similar beds, but not so carbonaceous in character. *Thinnfeldia* and *Baiera* were obtained from some of these shales. According to evidence obtained in the Molteno Division, the Molteno coal occurs at a horizon of about 300 feet above the Indwe coal. On Patrys Fontein these adits are evidently at

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about the same distance above the base of the Indwe sandstone, hence I think we have here the horizon of the Molteno coal.

The Indwe sandstone can be followed from Patrys Fontein across the Eland's Laagte Spruit to Stryd Fontein, where it crowns a plateau of a considerable extent. The road from Aliwal to Jamestown has been carried up over this elevated ground, and in one of the cuttings the position of the Indwe coal is indicated by a series of peculiar hard black carbonaceous sandstones, with thin streaks of coal. The krantz of sandstone is prominent at Plaat Kop and Roodewal, along the Kraai River. On the latter farm several shallow boreholes have passed through the Molteno beds into the red and green shales of the Burghersdorp series.

About a mile and a half south-east of the farmhouse there are several drives into the hillside, exposing yellow mudstones, black carbonaceous shales, and impure coals, but showing nothing that seems promising.

Some of the shales are crowded with leaves of *Phoenicopsis elongatus*, while *Baiera schenki* and *Thinnfeldia* occur less commonly. The Indwe sandstone is present a little below these beds, and extends westwards, forming cliffs on either side of the Klip Spruit; owing to a dome in the strata, it is visible as far as the outspan on Kalkoen Krans.

About two miles north of the latter spot there is an exposure of shale along the Jamestown road which is crowded with plant remains, *e.g.*, *Thinnfeldia odontopteroides*, including several large fronds with stout rachis,* *Stenopteris elongata*, *Baiera schenki*, *Phoenicopsis elongatus*. This horizon is rather above the Indwe sandstone. Up the foot of the Stormbergen the Molteno beds form flats, which are covered with sandy soil and grass, with here and there a projecting edge of gritty sandstone. On Ruigte Valley a borehole was put down, and a seam of coal 2 feet 3 inches passed through at a depth of 163 feet. The hole was continued a little over 100 feet deeper, but the Indwe sandstone was not encountered.

Around Jamestown there is an area of Molteno beds almost entirely hemmed in by ridges of Red beds.

At Jamestown itself Schulp Spruit runs between cliffs of massive false-bedded felspathic grits.

On Wit Kop (so called from the two conspicuous volcanic necks filled with white tuff), a little north of the outspan, is a ridge over which the road to Telemachus Kop passes. Almost at the summit of the rise are thin beds of greenish sandstone crowded with plant remains. These are chiefly impressions of a fern, which Mr. A. C. Seward thinks is either *Thinnfeldia odontopteroides*, or very closely allied to it. *Taeniopteris* also occurs.

* These specimens are almost identical with forms figured in the Memoirs of Geol. Survey of N.S. Wales. Palæontology. No. 3. Plates XXIII.–XXV. 1890.

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A little beyond the farmhouse, near this spot, fragments of silicified wood strew the ground, and there occur in among the blue, grey, and buff shales pinkish and reddish bands ,one of the very few examples of such coloured rocks in the Molteno beds of this district. On Modderpoort thin coaly seams occur close to the bridge over the Telemachus Spruit. Molteno beds extend down the latter to its junction with the Holle Spruit, but the continuity of the strata is much disturbed by numerous dolerite dykes and sheets.

The country on the south-west side of the Kraai River is undulating, and outcrops, except of pebbly sandstones, infrequent. On the farm Broeder's Bank, on the right bank of the Kraai River at the drift, fossil wood is abundant.

Dr. Watson, of Aliwal North, gave me a portion of a reptilian mandible which had been obtained from Klipplaat Fontein (ad joining Broeder's Bank). The bone was not, however, found *in situ*, and as reptilian remains are almost entirely absent from the Molteno beds, I think that it must have been brought down by the river from the Red beds above Kraai River Poort.

At Bosjes Laagte (between the Kraai River and Lady Grey) an alternating series of green and purplish mudstones is visible at the drift on a horizon a few hundred feet below the base of the Red beds.

Between the Kraai and the Orange Rivers there are extensive grass-covered sandy flats. The upper sandstones of the Molteno beds are harder and more gritty than farther west, and consequently form flat-topped hills and ridges.

A large number of thin dolerite dykes run across country in various directions, often for considerable distances.

Passing now to the description of the Molteno beds along the Orange River, we have first of all the ridge between the latter and the Kraai River Bridge. As mentioned some distance back, it is capped with the massive Indwe sandstone, in places overlain by dolerite.

The same sandstone edges the plateau up which the road ascends to Limoen Fontein. The slopes are very steep, and in constructing the road advantage has been taken to make a cutting along a decomposed dolerite dyke occupying a line of fault. On Mooi Fontein there is a cliff, close to which the road runs, and a very good section of the sandstone is afforded.

It is about 150 feet thick, fine-grained, and grey in colour towards the base; in the middle come bands and lenticles of ironstone nodules, with abundant impressions in limonite of indeterminable plant stems. The upper beds are of coarse-grained pebbly sandstone, but usually finer in texture than is the case in the Transkei or at Indwe. Higher up are finer-grained sandstones, with shales and mudstones, then soft pinkish felspathic grits.

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At Limoen Fontein, close to the hotel, is a pale blue mudstone crowded with *Thinnfeldia*.

The Indwe sandstone forms krantzes on the banks of the Orange River, and is probably represented by the thick sandstone on Elsje's Kraal and Wilge Spruit, on the Herschel boundary. The sandstone is very irregularly bedded, and contains lenticles of bright shiny coal. One of these at a point opposite the extreme south-east corner of Elsje's Kraal has a maximum thickness of six inches. Higher up the river, on the farm Wilge Spruit, there are good exposures of dark shales, with coaly material. The following is a section at a point about a mile and three-quarters above the homestead:—

Very impure coal...	6	inches.
Sandstones and mudstones	36	„
Dark shale, with thin laminae of coal	20	„

The lowest bed is crowded with plant remains, chiefly *Phoenicopsis* and *Thinnfeldia*. These strata were proved again in a borehole close beside the homestead. The upper coaly seam is very persistent, and is seen again in the north corner of Maudsley, overlain by shale and river gravels.

In the spruit close to the store on Maudsley is a small exposure of an impure black fireclay containing fronds of *Thinnfeldia*, probably *T. rhomboidalis*. Its thickness is uncertain, as its upper surface is eroded and overlain by river gravels and alluvium. On the same farm, but just beside the homestead, is an outcrop of soft mudstone, with plants such as *Thinnfeldia* and *Baiera schenki*; *Pachypteris* is probably also represented. Close at hand in the river is a massive bluish sandstone, with a bed of ironstone conglomerate. The probable thickness of the Molteno beds along the Wilge Spruit is about 900 or 1,000 feet.

None of the exposures of coal in Aliwal North are promising, but as the greater part of the district has not been prospected, and as the softer beds are not exposed, as a rule, it may well be that payable coal seams exist. The seams hitherto found are thin, and appear to run regularly for considerable distances, so that there is usually little hope of their thickening when followed. A company has been formed to exploit the coals around Patrys Fontein, but the prospects, as will be gathered from the description already given, are not very encouraging.

(iii) *The Molteno Beds in Herschel.*

Only a comparatively small portion of Herschel is occupied by Molteno beds, namely, the low ground between the Wilge and Sterk Spruits and an irregular strip along the Orange River up to the border of Basutoland.

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Throughout this area exposures of dark shales are remarkably rare and plant-bearing strata rather uncommon. The deep gorge in which the Orange River flows from the Wilge to the Bamboes' Spruit, has many krantzes of thick sandstone, both fine-grained and gritty; sometimes with lenticles of black shale and coal.

Some of this coal was sent down to Cape Town for analysis, together with material obtained by Mr. Brigg from the farm Wilge Spruit,* while Mr. Bain made a report upon the localities.† At the Wittebergen mission station shales with *Thinnfeldia* occur.

On the rise overlooking the village of Herschel there are mudstones with striated stem fragments, probably those of *Schizoneura*. About three miles due north of Thomas's store, "Blue Gums," at a bend in the Orange River, there is a fine cliff a couple of hundred feet in height, giving very good exposures of dark blue and green mudstones, but no carbonaceous layers occur.

At Bamboes Spruit, on the right bank, close to the wagon road, there is an outcrop of shaley material.

The section is as follows:—

5. Soft friable ochreous sandstone.
4. Black shale ... ... 18 inches.
3. Hard dark shaley mudstone ... ... 3 "
2. Black shale ... ... 6 "
1. Thick friable sandstone, with fragments of carbonised wood in abundance.

The beds are disturbed by dolerite intrusions, and have a maximum dip of about 45 degrees westwards. Curiously enough, none of the beds contain any recognisable plant remains. A little way up the Bamboes Spruit is an outcrop of hard pale-bluish grey flinty rock (due to contact with dolerite), containing plant remains in a remarkably fine state of preservation.

Thinnfeldia odontopteroides is abundant, while there is also a species of *Ginko*.

Near Bensonvale *Thinnfeldia* was obtained from a hard white porcellanite, at the top of the formation. In the eastern part of Herschel there are two small inliers of Molteno beds, from neither of which were any plant remains obtained. The first of these is at Tyinindini, on the river running down from Majuba Nek to join the Telle River.

The outcrops show thick grey felspathic sandstones and dark blue-grey to blue-black arenaceous shales and mudstones.

* Papers and Correspondence regarding Colonial Coal, p. 5 and 14, 1891; analyses given.

† Ibid, p. 17.

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Similar beds crop out in the Telle River from a point a little above its junction with the Blikana River to about a mile above Dilli-Dilli. Here are exposed thick yellow-weathering sandstones, with dark mudstones and shales, sometimes containing thin purplish bands.

Throughout the whole of Herschel there was not a single coaly bed noticed which would be suitable for burning, but it must be mentioned though that very little prospecting has been done, and that most of the low ground is grass-covered.

IV. The Red Beds.

(i) *In Wodehouse.*

As has been already noted, the Red beds cover the whole of the north-eastern half of Wodehouse, except where narrow tongues of Molteno beds are exposed in the valleys. This is the case with the valleys of the Wolve Spruit and Holle Spruit, but the Waschbank River throughout the whole of its course flows over Red beds.

The reason for this is two-fold. In the first place, there is a general north-easterly dip of the strata, and consequently the summit of the Molteno beds would occur at a greater altitude at Dordrecht than in the Waschbank valley. In the second place, the Red beds are considerably thinner in the west than in the east and south-east of the division.

The base of the formation is not always easy to define, owing in great part to the presence in it of coarse "glittering" sandstones like those of the Molteno beds. In many places, too, the colouring matter has been removed by weathering, and the rocks are now pinkish or yellow. A most notable example of this bleaching is found on the ridge separating Teken Fontein from Waterfall, about 17 miles north-east from Dordrecht. At this place, from the foot of the rise to the summit, a vertical distance of over 400 feet, scarcely a single red or purple bed is exposed, whereas a few miles away along the hillside in these same beds the red colour is well developed. It is possible that in this case there might have been less colouring matter in the rocks than is usual, so that they were more readily bleached.

The upper limit of the Red beds is, as a rule, well defined, and the junction with the Cave sandstone is often extremely sharp. Sometimes the Cave sandstone is pinkish in colour and slightly bedded towards the base, and when weathered can hardly be distinguished from some of the upper sandstones of the Red beds. Such a case is illustrated by the ridge separating the Wolve Spruit from the Waschbank River on the farms Schilder Krantz, Coetzee's Kraal, and Wolve Kloof. Here the hills are capped with a thin bed of yellowish sandstone, which might have

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been grouped with the Red beds had not an outlier of Cave sandstone capped with lavas occurred close at hand on the same stratigraphical horizon.

With the lower and upper limits of the Red beds thus defined, it is found that the thickness of the series varies considerably in different parts of the district.

Below Xalanga Peak and just north of Indwe the Red beds attain a thickness of 1,500 feet,* but when followed along the watershed towards the west the formation thins rapidly.

Thus on Leeuwen Fontein, thirteen miles north-east of Dordrecht, a full section of the beds is shown on the hillside north of the main road, and the thickness is found to be only 650 feet. Hence in a distance of about twelve miles a diminution of thickness amounting to 850 feet, or over one-half, has taken place, which is all the more remarkable because both farther east and farther west the strata maintain their thicknesses nearly uniformly. Thus between Dordrecht and Jamestown the thickness is usually about 600 feet, which is in complete agreement with Dunn's value for the Red beds in the Molteno division.†

In the lower portion of the Waschbank valley the formation is thicker; thus on Andover, close to the Kraai River, red shales and clays are exposed at various horizons in the kloofs right down into the bed of the river, giving a minimum thickness to the Red beds of 900 feet. As the Molteno beds crop out in the Kraai River a little to the north-east of this point (at its junction with the Holle Spruit), it is evident that the thickness of the Red beds hereabouts must lie between 900 and 1,000 feet.

A little further towards the east the strata dip rapidly eastwards, and the Red beds are carried down below the bed of the river, but it is probable that they maintain a nearly constant thickness below Barkly East.

The Red beds in Wodehouse are of very similar character to those of Elliot and Aliwal North. The most brilliantly coloured beds occur just below the Cave sandstone in a vertical distance of from 400 to 500 feet, as, for example, along the main road between Wolve Kloof and Siberia, where good sections are exposed in the numerous road cuttings.

Farther north the Waschbank River flows between lofty red cliffs, capped by yellow Cave sandstone.

In some places the beds are bleached, but the original colour of the strata is often shown through the occurrence of landslips on either bank.

The lower portion of the Red beds, well exposed in the Waschbank valley from the farm Willow Kloof to the Kraai River, shows banks of rather coarse-grained gritty sandstone, pale

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* Ann. Rep. Geol. Com. for 1903, p. 190, see also Map of the Stormberg Coal Fields by E. J. Dunn.

† Dunn. Report of the Stormberg Coal Fields. Cape Town, 1878, p. 4.

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yellow or bluish in colour, and from fifteen to twenty feet thick, with interbedded yellow and buff mudstones and thin purplish-red sandstones, shales, and clays.

These sandstone beds are thicker, coarses in character, and spaced closer together than is the case in the same formation in the Elliot division.

Calcareous rocks are frequently found in the Red beds, seldom in definite layers, but more commonly in the form of irregular nodules and concretions of a bluish or pinkish colour in some of the mudstones. Some of the concretions are extremely ferruginous, while in places the sandstones may be heavily impregnated with ferric oxide—for example, at Siberia and Stryd Poort.

Organic remains were found at various localities in the Red beds. Silicified wood is common, usually in fragments, but occasionally large stems are found embedded in the rock, as, for example, on the farm Stryd Poort in the Waschbank valley.

Fossil bones are not uncommon, but nearly always in small fragments weathered out of red calcareous nodules.

At Wolve Kloof a bed of shale is exposed in the road cutting at the southern entrance to the "poort," and contains remains of plants and *Estheriae.* The shale is blue in colour, becoming more arenaceous in character towards both base and summit, and is about eight feet in thickness. There can be no doubt that this belongs to the Red beds, for exposures of purple-red sandstones and mudstones are visible in the river bed about a hundred yards to the south.

From this bed were obtained a fragment of *Thinnfeldia,* another of a fern, possibly *Laccopteris* (a genus new to the Colony, but which occurs in the Rhaetic and Jurassic of Europe), several fragments of finely-striated stems and numerous small valves of *Estheria.*

(*ii*) *In Aliwal North.*

The Red beds in this division form the upper portion of the range known as the Stormbergen in the south-west, and constitute all the high ground around Jamestown and on both banks of the Holle Spruit and Kraai River. The formation also builds up the plateau whose escarpment runs from the junction of the above-mentioned rivers, near Kraai River Poort, in a north-easterly direction to Lady Grey.

Only one journey was made into the Stormbergen, but it was sufficient to show that the area would require careful and detailed mapping on account of the great volcanic centre of Telemachus Kop. I had, unfortunately, no more time to spend in this part of the country.

A little north of the Stormbergen and between that range and the Kraamberg is a peculiar isolated peak called Hopley's Berg. This mountain is capped with a couple of hundred feet of Red

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beds, which are parted near their base by a slightly inclined sheet of columnar dolerite. It is probably owing to this intrusion that the strata have been able to resist denudation so successfully, thus giving rise to the most northerly outlier of Red beds west of Aliwal North.

The base of the formation has an altitude of about 5,700 feet above sea-level, and the strata dip gently towards the south-east. On the farm Meerder Wyk, on the north side of the Stormbergen, there was obtained by Mr. Alfred Brown, of Aliwal North, the remains of a large dinosaurian, apparently from the base of the Red beds.

It has been named *Euskelesaurus brownii* by Huxley,* and according to Seeley,† is allied to *Zanclodon* and *Megalosaurus*.

A little north-east of Jamestown are two nearly parallel ridges, which trend north-west, south-east, and whose existence is due to two great dolerite intrusions along their lengths. Red beds extend along the ridges from the Stormbergen to the high ground on Vaalbank and Klipfontein, about seven miles to the north-east at Jamestown. To the south-east of Jamestown there is a great area formed by Red beds, capped occasionally by Cave sandstone, and extending along the west bank of the Holle Spruit in the direction of Dordrecht. This portion of the country has been mapped by E. J. Dunn, and in consequence my geological lines were only traced far enough westwards to join up with his, the re-examination of the area being deferred for the present. On the north-east boundary of Vogel Fontein, at the head of the Telemachus Spruit, a mountain side rising very steeply for a distance of about 800 feet shows very clear sections of the Red beds towards its summit. The formation contains many beds of yellowish and reddish sandstone, much thicker and spaced closer together than is usually the case.

On the south side of Telemachus Kop a number of fragments of reptilian bones were obtained from some purple-red mudstones and clays.

On the farm Olyven Kloof, on the Telemachus Spruit, close to its junction with the Holle Spruit, the base of the Red beds is very clearly defined. A thick yellow sandstone bed forms the separating rock between the Molteno beds and the overlying purple and red shales and mudstones.

This sandstone, which forms a small cliff along the hillsides, weathers away more rapidly across the lower half of its face, and is thus undercut to a certain degree; the colour of the eroded surface is very much lighter than the unaffected portion. It is curious to find that about 20 miles away to the north-east a bed of sandstone with similar characters occurs again at the base of the Red beds. The contrast between the dark pitted upper

* Huxley. Quart. Journ. Geol. Soc., Vol. xxiii., 1867., p. 1.
† Seeley. Ann. Mag. Nat. Hist. Ser. 6, vol. xiv., 1894, p. 317.

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portion and the smooth light-coloured eroded lower half is very marked.

This second occurrence is on the farms Klip Fontein and Riet Fontein, between the Kraai River and Lady Grey. Owing to the undercutting of the sandstone immense rectangular blocks have broken off, and now strew the hillsides.

At Flaauw Kraal the strata dip inwards, and form a basin, the inclination being in places as high as six degrees.

The Holle Spruit, which throughout the rest of its course flows over Molteno beds, crosses this basin, and along a distance of about six miles has its banks formed of Red beds.

At Kraai River Poort, the river, after its junction with the Holle Spruit, emerges from a deep winding gorge with precipitous sides. The first few hundred feet above the river bed are Molteno beds; then come 900 feet of Red beds, and the ridges are capped with from 200 to 300 feet of Cave sandstone, often forming unscaleable cliffs.

The former extension of the old plateau (with an altitude of about 6,000 feet above sea-level) is indicated by numerous flat-topped hills in the immediate neighbourhood, impressing on the observer the magnitude of the denuding action which has affected this part of the country. One peculiar conical hill is capped with a small circular area of Cave sandstone somewhat jagged in outline, and has been rather appropriately named "King's Crown." A little more than a mile from it is another conical peak, but the sandstone capping is a mere remnant, and the tiny pyramid is cut through by two vertical dolerite dykes, which intersect at an angle of about sixty degrees.

At Klip Fontein, a little north of Kraai River Poort, the uppermost sandstone of the Red beds caps a long spur, and gives the ridge the appearance due to an outlier of Cave sandstone.

The Karnmelk Spruit, which takes its rise in a valley carved out of the lavas in the extreme eastern corner of the Aliwal North division, has cut a deep and very narrow gorge through the Cave sandstone into the Red beds just below the bridge on the main road to Barkly. The fall of the river is remarkably rapid, and as the strata have a gentle easterly dip, the Molteno beds have been exposed in the lower reaches of the river. The ground is much cut up on either bank, and it is extremely difficult indeed to make any detailed examination of the beds.

Fine exposures of the Red beds occur around the Karnmelk Spruit hotel, giving wherever the rocks are freshly exposed a brilliant scarlet colour to the hillsides. A few fragments of bone were found in the neighbourhood embedded in a red calcareous sandstone. The main road from Karnmelk Spruit hotel to Lady Grey for a number of miles winds along the escarpment of Red beds which overlooks the flats of Molteno beds to the north-west, and many good sections are afforded by the road cuttings, especially on the farm Bamboes Kloof. A little east of the

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homestead, a single small vertebra was found in the bed of a stream; the specimen was evidently washed out from the beds higher up.

Dr. Broom says that the bone is "a dorsal vertebra of a medium-sized carnivorous Dinosaur allied to *Massospondylus*, but a rather smaller animal than *M. carinatus* (Owen)."

The town of Lady Grey (5,480 feet) is hidden away from view in a narrow kloof in the western end of the Witteberg range. Red beds form spurs on both north and south, capped by Cave sandstone and Volcanic beds, and the breadth of flat ground between the cliffs is under half a mile. On the north and north-west the mountain range forms a lofty wall for a number of miles further, up to the farm Welverdiend, on the Herschel border. On the south and south-east there is a dolerite dyke in the Red beds forming a low ridge, and in consequence the town is hemmed in on all sides. There is only one road out from the town; this runs westwards, and then branches, giving routes to Herschel, Aliwal, and Barkly.

From the strata forming the cliff overlooking the south side of the town fragments of reptilian bones of dinosaurian (?) type were obtained. One of these is a portion of a cervical vertebra, which measures six inches across the vertical diameter of the posterior articular surface.

Bones were also obtained from a point about two miles west of Lady Grey.

Mr. Lawrence, the Magistrate, gave me a portion of bone which he had obtained from this spot. Dr. Broom states that the bone is the head of a tibia belonging probably to the dinosaurian *Orinosaurus capensis** (Huxley and Lyddeker), the type of which was obtained by Mr. Alfred Brown from the Stormbergen (Meerder Wyk).

The Red beds on Zachte Vlakte contain rather coarse-grained gritty sandstones, yellow to brown in colour; silicified wood is of common occurrence. The junction with the Molteno beds is not well defined; there are no good sections, as the country is covered with soil and grass. Perhaps it may best be taken at a horizon below which conglomeratic false-bedded sandstones, with numerous pebbles of white vein-quartz, are well developed —for example, on Welverdiend. A little lower down in the series yellow mudstones occur, with striated stem and leaf fragments. The spur separating Welverdiend from the Herschel division is formed of Red beds, capped with a large outlier of Cave sandstone and lavas. A small detached area of the sandstone has weathered into peculiar pinnacles, and is known locally as "The Lions."

The thickness of the Red beds at this point, almost on the Herschel boundary, is not more than 600 feet, while the dip is at a low angle to the south-east.

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* Brit. Mus. Cat. Fossil Reptilia and Amphibia. Part IV., p. 253. 1890.

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Four small outliers of this formation occur between Lady Grey and Aliwal, two of them on Bult Fontein, close to the new railway, one on the hill overlooking Limoen Fontein (eighteen miles west of Lady Grey), and one at the northern beacon of Beer Fontein.

(iii) *Red Beds in Herschel.*

In the extreme west of the district, in the big loop formed by the Orange River, is an elevation rising to an altitude of about 5,500 feet, or 900 feet above the bed of the river. Reddish bands occur near the summit, so that probably we have here an outlier of Red beds. The ridges on the opposite side of the river, in the Orange River Colony, are lower, and consequently composed solely of Molteno beds.

The spur of Red beds between Welverdiend and Herschel village owes its existence to a rather peculiar sill of dolerite.

On the south the dolerite is seen dipping southwards; it rises rapidly up the side of the spur, becomes horizontal just below the summit, and descends towards Herschel village with a north-easterly dip, which it maintains until it reaches the Orange River. A section through the spur would thus show the sill of dolerite to have the form of an anticlinal arch, the igneous rock not rising as high as to cut the capping of Cave sandstone on the ridge.

Immediately to the south-east of Herschel there is a wide smooth slope covered with a deep layer of soil, and extending up to the base of the mountains; hence the junction with the Molteno beds is not exposed. The ground rises rapidly, and we get an extremely fine section of the upper portion of the Stormberg series.

For a vertical height of at least 500 feet and along a horizontal distance of about three-quarters of a mile all the surface soil and weathered material has been removed, giving a brilliant crimson-coloured cliff. The junction with the cream-coloured Cave sandstone is remarkably well defined, and above the cliff formed by the latter comes a great pile of dark coloured volcanic rocks. Seen from a distance the bed of Cave sandstone forms a broad white band along the side of the mountain range, and hence the derivation of the name "the Wittebergen." Between Bamboes Spruit and Bensonvale the colouring of the Red beds is not very prominent, but a little farther east up the Sterk Spruit valley, at the spot known as Josanna's Hoek, there are numerous narrow gorges cut through bright red and purple sandstones and clays. The Wesleyan mission station at Bensonvale is located in a narrow enclosed valley, surrounded by dolerite. The latter consists of a sheet, with low dip towards the north-east, through which the river has sawn its way. The

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floor of the valley is formed of Molteno and the sides of Red beds and dolerite, the river passing through a "poort" on the north.

In cuttings along the road leading from Bensonvale to Josanna's Hoek, red and purple mudstones are exposed just below the dolerite, and must belong to the very base of the Red beds, for at the poort *Thinnfeldia* was obtained from a baked yellow shale on a horizon about 50 feet lower, these strata being considered to belong to the Molteno group. From Josanna's Hoek the lower boundary of the Red beds trends northwards, tongues of the formation projecting out towards the west and north-west along the ridges separating the various small spruits which drain into the Orange River. Outliers occur occasionally —for example, on a dome-shaped eminence a couple of miles west of Sterk Spruit and on a pyramidal-shaped mountain to the north, known as Prospect Peak.

The boundary passes close to Governor's Drift, and then runs north-eastwards to the bend in the Orange River at the point where the Maputsang River comes down from Basutoland to join it.

With the exception of the two small inliers of Molteno beds at Tyinindini and Dilli-Dilli, already mentioned, all the eastern portion of Herschel is built up of Red and higher beds.

At Dulcie's Nek, between Sterk Spruit and Palmietfontein, a bed of limestone occurs at the summit of the Red beds, the locality being high up the mountain side. The rock on being burnt yields a lime of fair quality, and the product has been utilised in the neighbourhood for building purposes.

Near Palmietfontein reptilian remains were found at a point three miles due south of the village. The bones were embedded in a hard greyish calcareous sandstone at a horizon about 180 feet below the base of the Cave sandstone.

Dr. Broom's remarks on the bones are:—"Most of the dorsal, a few cervical, and a number of caudal vertebrae, with two phalangeal bones of a small Carnivorous Dinosaur of about the size of *Hortalotarsus skirtopodus*, but not belonging to that genus, and apparently more nearly allied to *Massospondylus*. It may possibly belong to the same genus as *Massospondylus* (?) *browni* (Seeley), but apparently does not belong to the same species."

About a quarter of a mile further south bones were also found embedded in red shale about 100 feet below the Cave sandstone.

The Red beds have a considerable thickness at Palmietfontein, 900 feet at least; for red and purple clays are exposed along the banks of the Telle River several miles above its junction with the Orange River. Similarly at the rise from Krom Spruit to Majuba Nek a thickness of about 900 feet of Red beds is met with, of which good sections are seen in the road-cuttings. The various tributaries of the Telle River, both in Herschel and Basutoland, have cut deep valleys in the Red beds,

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On the north side of the Witteberg range the main valleys as they approach the mountains, branch and give rise to a radiating system of narrow gorges, separated by spurs capped with Cave sandstone and Volcanic beds. The dip of the strata along the Telle River is northwards, *i.e.*, down stream; this is especially noticeable as the observer looks down the valley from the summit of Lundean's Nek. The Red beds stretch from the Telle River into Basutoland up the valley of the Orange River, evidently for a considerable distance. From Moyena (in the Quthing division) a fine view can be obtained north-westwards over Herschel and the Orange River Colony and north-eastwards towards Natal. In this direction, as far as one can see, almost to Fort Hartley, the Red beds appear in the lower portions of the valley, while the Cave sandstone forms long white cliffs on either side, topped by Volcanic beds, building up endless serrated ranges of mountains, often of considerable altitude.

Fine cliffs of Red beds can be observed just below Moyena, where the Silver or Masitisi River has cut itself a very deep and narrow gorge.

At Masitisi mission station a purple-red calcareous sandstone was noticed, containing a few fragments of small bones and scutes, probably belonging to a crocodile of the same genus as that obtained from Barkly East (*Notochampsa*).

On the bank of the Masitisi River, quite close at hand, remains of a dinosaurian reptile were obtained many years ago by Mr. Alfred Brown, of Aliwal North. Mr. Brown informs me that the bones were embedded in a decomposed reddish shale; and from his description the horizon must be in the lower portion of the Red beds.

The remains were provisionally described by Professor Seeley* as *Massospondylus* (?) *browni*, but at the same time he notes that his identification is not absolute. Dr. Broom informs me that the fossil is probably not *Massospondylus*, and cannot be a species of *Hortalotarsus* (of which a well-preserved specimen is now known).

The Red beds extend northwards along the western border of Basutoland towards Mohalle's Hoek and Morija, while the Molteno beds form the flats over which the Kornet Spruit flows.

(iv) *Red Beds in Barkly East.*

In the central portion of Barkly East, at Eagle's Crag, the Kraai River is joined by the Joachim Spruit and its tributaries, which take their rise in the mountains to the north. These rivers have cut down through the Cave sandstone into the underlying Red beds, producing an inlier of the latter, with a highly irregular outline.

* Seeley. Ann. Mag. Nat. Hist., ser. 6, Vol. XV., 1895, p. 118.

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The general dip of the strata is southwards, from Lundean's Nek towards the Kraai River, but at Eagle's Crag there has been a bulging upwards of the beds with the formation of a flattish dome.

The Kraai River traverses the southern margin of this dome, and on Lower Drumbo several hundred feet of Red beds are exposed along its banks. A good section, showing the junction of this formation with the Cave sandstone, is to be found along the Kraai River, at the eastern boundary of Kelvingrove. The dip of the beds is south-eastwards at an angle of as much as twenty degrees, but the inclination is probably in great part due to the proximity of the great volcano of Belmore. The section visible is as follows:—

Cave sandstone	4. Pale yellow sandstone. 3. Red clay, with irregular white quartzitic concretions. 5 feet.
Red beds.	2. Sandstone, varying in colour from pale pinkish to dark purple. 6 feet. 1. Red clays. 15 feet exposed.

The bed of sandstone (2) is rather variable both in thickness and in tint; where bleached it is almost cream-coloured.

From this bed there was obtained many years ago a reptilian skeleton known locally as the "Bushman Fossil," but the slab in which the bones were embedded, and which was about four feet in length, was unfortunately broken up. Some of the fragments were sent to the Albany Museum, Grahamstown, and were described by Professor Seeley† under the name of *Hortalotarsus skirtopodus* (Seeley).

Quite recently the South African Museum has been presented with a fossil from the Cave sandstone of the Ladybrand division of the Orange River Colony. This when developed by Dr. Broom proved to be a better preserved specimen of *Hortalotarsus*, and showed great affinities to the American dinosaur *Anchisaurus* (*Marsh*), the similarity of the genera having been to some extent already noted by Seeley. From the same horizon, within a few yards of the spot where the Eagle's Crag fossil had been found, I obtained the remains of a small crocodile embedded in a mass of purplish sandstone. The fossil has been developed by Dr. Broom, and by him named *Notochampsa longipes* (Broom).‡

Along the Joachim Spruit, on the farm Fetcani Glen, the main road has been cut in beds of friable dark blue shale, dark red shale, and thinly-bedded sandstones, which have a combined

† Ann. Mag. Nat. Hist., ser. 6, Vol. XIV., 1894, p. 411.

‡ Geol. Mag. Dec. V. Vol. I., No. 12, p. 582, 1904.
The bones according to Dr. Broom consist of "the somewhat displaced remains of a small crocodile allied to *Notochampsa istedana* and not improbably belonging to the same genus. The remains consist of a number of the dorsal, ventral, and caudal scutes, the right arm, and both hind limbs and pelvis. In all respects *Notochampsa* is a typical Jurassic crocodile."

thickness of about twenty feet. The river flows between cliffs formed of a massive white sandstone from fifteen to twenty feet thick immediately below these soft beds, and underlain by red sandstones and mudstones. At first sight it would seem best to include this sandstone with the overlying strata in the division of the Cave sandstone, but a little to the north the thick arenaceous bed is replaced by red sandstones and shales, consequently it has been grouped with the Red beds.

On Fetcani Glen a thin reddish-purple sandstone occurs, which is split up naturally into long narrow strips, usually about one to two inches thick and eight to ten inches deep. These narrow slabs can be taken out in lengths of as much as eighteen feet, and are very valuable for fencing poles. The sandstone contains peculiar discoidal concretions of finer-grained material from the size of a button up to two inches in diameter. In outline they much resemble nummulites. The joints in the sandstone do not pass through these concretions.

On Glencoe the Red beds contain much silicified wood, and some of the tree-stems are of considerable size.

On Glencoe and Glengyle there is a thin, almost horizontal sheet of dolerite intrusive in the Red beds, a most exceptional type of intrusion in Barkly East, where almost all the dolerite occurs in the form of vertical or highly inclined dykes.

The sheet runs very uniformly on the east bank of the spruit, where it caps a lofty cliff, but bursts through the strata on the west bank in a highly irregular manner. The Red beds extend in a tongue up the valley of the Joachim Spruit as far as Glen Lyon at the foot of the ascent to Lundean's Nek. Fine cliff sections are laid bare on the east bank of the stream where the main road crosses. A number of narrow dolerite dykes traverse the strata between Wartrail and Glen Lyon.

A second inlier of Red beds occurs about five miles east-south-east of Belmore, in the valley of the Bok Spruit (marked Kraai River on the divisional map).

The exposure is only a little over two miles in length, and is due to the removal by the river of the overlying Cave sandstone at a point where the strata are bent into a very gentle dome.

In the valley of the Sterk Spruit two narrow inliers of this formation are exposed. The first of these extends from Lisburn to Carrig Bawn, a distance of four miles, and though not more than 40 feet of Red beds are exposed, the junction with the Cave sandstone is extremely well defined.

On Carrig Bawn a dolerite dyke crosses the valley in a north-east, south-west direction into the Elliot division., The igneous rock contains a small amount of tarry oil in crevices and cavities. The bituminous material must have been brought up from below, for the dyke does not penetrate the Volcanic beds above the Cave sandstone. If the material has been produced by the distillation of coal or carbonaceous shale, it must have been brought

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up from the Molteno beds from a depth of not less than close upon 2,000 feet.

A little higher up the valley, on the farm Athol, red shales and sandstone crop out in the bed of the stream along a distance of a little over a mile.

V. The Cave Sandstone and Volcanic Beds.

These uppermost divisions of the Stormberg series are so intimately connected in this area that it is impossible without considerable repetition to describe each of them separately.

Almost the whole of the division of Barkly East, and the neighbouring portions of Elliot, Wodehouse, Aliwal North, and Herschel is occupied by them. In Herschel, too, the central mountain ranges are built up of Cave sandstone and Volcanic beds, while in Basutoland they cover an immense area, as the Red beds only crop out in the narrow river gorges.

Outliers of Cave sandstone are common along the Holle Spruit and in the Stormbergen.

The lower of these two formations consists of a fine-grained sandstone, usually pale yellow in colour, but white, buff, pink and bluish varieties also occur in different localities.

Generally, it is unbedded throughout its thickness, which in this area varies from about 150 to 800 feet. This character is not usually so well-pronounced at its upper limit, for in many places the sandstone then becomes laminated. False-bedding is not uncommon, and is sometimes extensively developed. The formation bears apparently a considerable resemblance to the massive bed of white Jurassic sandstone recorded by Dutton, from the Grand Canon region in Arizona.*

In a few places the Cave sandstone is entirely unrepresented between the Red and the Volcanic beds. In some places, and this is especially true in Barkly East, the sandstone is split up by numerous beds of lava and ash. Under the microscope the sandstone is seen to be very uniform in texture, the rock being built up chiefly of grains of clear quartz, which are only to a small degree rounded. There are angular fragments of orthoclase, microcline, and plagioclase, little grains of zircon, epidote, and occasionally tourmaline. In this respect it is very much like most of the finer sandstones from the Molteno or the Red beds, except that there are very few or hardly any dark-coloured mineral grains in it.

A view has been advanced that the Cave sandstone is partly at least of volcanic origin, and that the material of which it is composed has been brought up from deep down below the surface of the earth, and represents shattered Cape and Pre-Cape rocks. I have not seen anything which might be construed into

* U.S. Geological Survey. Monograph II., p. 35, 1883.

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affording any support for this theory. In fact, the more the Cave sandstone is examined the more is the conviction forced upon me that it is a normal type of sediment derived from a land surface composed principally of quartzites, granites, and metamorphic rocks. It has been argued that the material filling many of the volcanic necks is identical with the Cave sandstone, but, as will be shown later, there is a certain amount of evidence to show that the material filling these tuff necks is in great part formed of sediment which dropped into the vents from above. The absence of quartzite, and more especially of granite, in the form of large masses or boulders is, I think, fatal to the theory. When it is added, too, that in many places the line of separation of the Cave sandstone from a bed of ash is perfectly sharp and distinct, the latter alone containing fragments of rocks which are recognisable as having come up from below (such as red shales from the Red beds), we may consider the sedimentary origin of the Cave sandstone as being quite certain. In chemical composition, too, the sandstone is quite normal, and the amount of alkalies present is by no means large.

Fossils are rather rare in the Cave sandstone, and, as a rule, are not very well preserved, owing to the porous nature of the rock.

From the shale-band at Siberia were obtained *Estheriae*, a number of small phyllopod crustaceans, a fore wing and also a hind wing of an orthopterous insect (Blattid), and the fore wing of another orthopteron (probably a Gryllid).

The vertebrate remains show dinosaurs and crocodiles, but fishes are also represented. Stow* also recorded the latter from the Cave sandstone north of Ficksburg (O.R.C.).

Silicified wood is not uncommonly met with in the sandstone, but plant impressions are rare, and too indefinite for determination.

With regard to the Volcanic beds, lavas, compact, doleritic, and amygdaloidal predominate, but beds of ash, and ashy sandstone occur as well, being, however, almost entirely confined to the division of Barkly East.

The Cave sandstone and Volcanic beds, in Elliot, on the southern border of Barkly East, have been described previously,† and it was recorded that just below Xalanga Peak the former was split up into two portions by a bed of doleritic lava.

As these divisions are followed along the western face of Xalanga Peak, on farm Paarde Kraal, the upper bed of sandstone thins out and disappears, while the lower one forms a continuous krantz above the right bank of the Waschbank River, maintaining a thickness of from 200 to 250 feet. Outliers of Cave sandstone occur on the ridges forming the watersheds between the

* Report of the Geological Survey of the Orange Free State, p. 48. Bloemfontein, 1879.

† Ann. Rep. of Geol. Com. for 1903. (p. 200).

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Indwe and Waschbank Rivers and the Walve Spruit and Woschbank River. On the farm Coetzee's Kraal, near Wolve Kloof, is a small outlier of Volcanic beds, the only example between the main mass east of the Waschbank River and Pronk's Berg, 30 miles to the west.

On this farm, too, as already noted, the Cave sandstone is sometimes bedded, and when forming a thin capping to the hills is difficult to distinguish from the uppermost sandstones of the Indwe and Waschbank Rivers and the Wolve Spruit and Wasch-the central portion of the bed of Cave sandstone is very soft and pale bluish in colour, disintegrating like a mudstone.

All along the right bank of the river the sandstone forms one single bed, but a little eastwards, in the gorge of the small river joining the Waschbank on Stryd Poort it is evidently parted by a layer of lava. On Stryd Poort, about a mile due east of the police camp, the lava sheet terminates like a wedge in the midst of the sandstone. The lower surface of this wedge of lava rests upon an inclined face of sandstone, due partly to thinning out of the beds themselves and partly to erosion. That the latter may easily have occurred here is clearly shown by the exposures two miles to the north, at Siberia. To account for the irregular deposition it is possible to assume that owing to some of the early eruptions the supply of sediment was diminished at this point, and that the obstruction was afterwards removed.

The upper surface of the lava is quite even, and is covered conformably by the sandstone.

This lava bed occurring almost at the base of the Cave sandstone is the earliest flow which has been detected in this area.

The most interesting section through the Cave sandstone is that which occurs at Siberia, close to the hotel and to the old police camp. The main roaa from Dordrecht to Barkly forms a series of zig-zags up the ridge, and there are very good sections in the dee proad cuttings. The following is a vertical section of the strata about 300 yards above the hotel:—

Cave Sandstone	20 feet.	Yellow-white massive fine grained sandstone.	
	3 to 4 feet.	Bright-red sandstone.	
	4 to 10 feet.	Sandy shales and thin bedded blue sandstones.	fossiliferous
		Blue-black shale.	
		Greyish to blue-black shales, arenaceous at base.	
	8 ft.	Massive pale fine grained sandstone.	
	½ ft.	Brilliant green arenaceous shale.	
Red Beds	2 ft.	Soft purple shales and mudstones.	
	20 ft.	Purple red sandstone and sandy mudstone (often very falsebedded).	

The thicknesses of the different beds vary considerably from point to point. The fossiliferous band of shale does not extend

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for more than about 400 yards along the hillside. The bed is full of small crustacean remains, remarkably well preserved; a list of the fossils has been noted already. It is very interesting to find such a number of new forms in the Cave sandstone. It is worth noting that Mr. Draper discovered a bed of dark shale in the Cave sandstone of the Platberg, near Harrismith (Orange River Colony), from which Professor Rupert Jones described† two species of *Estheria*, *E. draperi* and *E. stowiana*. The beds at Siberia contain an *Estheria* probably identical with *E. draperi*, and also a smaller species, which may turn out to be new. The shale-band is fossiliferous, even in those portions which are rather arenaceous. The beds also contain irregular whitish spongy nodules an inch or two in diameter, which resemble coprolites. They only contain a small amount of phosphate of lime, however. It is worth noting that at Morija, in Western Basutoland, a thick blue shale bed is present in the Cave sandstone, in which Mr. Dornan, of that place, has succeeded in finding reptilian remains. At Siberia the Cave sandstone is not very thick—in fact, a little way further up the valley it is reduced to an insignificant stratum. That its original thickness must have been much greater is shown partly by the lofty cliffs which it forms lower down the valley and partly by the nature of te sections along the main road.

A study of the outcrops shows that there are at least three faults, each with a throw of about 30 feet, which have displaced the Cave sandstone and Red beds alone. The upper portion of the Cave sandstone has then been eroded, giving a rather wavy surface, upon which the Volcanic beds rest without any sign of disturbance. Here we have the clearest evidence both of faulting and erosion before the overlying lavas were poured out, thus confirming the conclusion which had been arrived at in regard to the reason of the great irregularity of the Cave sandstone below Xalanga Peak in the Elliot Division.*

These disturbances in the strata were probably due to earthquakes attending the formation of volcanic necks in the neighbourhood. The erosion was probably sub-aqueous.

About 100 yards from the hotel there is a peculiar mass of lava intruded in the Red beds, a dyke rising and spreading out as a thin sheet on the left-hand side of the valley. The rock is compact in some places, but more commonly it is vesicular, with large cavities filled in with quartz and calcite. This is probably a fissure formed close to a volcano (situated farther east), and filled with lava. It must be noted that the lava sheet parting the Cave sandstone on Stryd Poort may be a sheet poured out from a volcano, also situated towards the east, possibly the same vent.

† Geol. Mag., dec. IV. Vol. I., p. 289. 1894.
* Rep. Geol. Com. 1903. p. 200.

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Above the main bed of Cave sandstone at Siberia there are three other sandstone bands interbedded in the lavas, two of them extending for considerable distances toward the north-west and south-east. The uppermost one dips in under the ridge forming the Barkly East boundary, and reappears in the Honey Nest Kloof at a lower altitude. A couple of miles north-west of Siberia, on the farm Craggy Glen, there is a very large cave in the main sandstone bed, on the north-west side of the gorge leading down into the Waschbank valley. From this cave Mr. Heüser, of Siberia, has obtained about two tons of saltpetre in a remarkable state of purity, the mineral having been found on the floor of the cave covered with animal refuse. The saltpetre is pale yellowish in colour, with a marked fibrous structure. An analysis made byMr. J. Lewis, of the Government Laboratory, shows the composition to be as follows:—

Potassium nitrate	94·431
Sodium nitrate	1·564
Calcium nitrate	·217
Magnesium nitrate	·051
Calcium sulphate...	3·197
Calcium carbonate	·066
Magnesium chloride...	·030
Calcium phosphate...	*trace*
Insoluble sand	·008
Moisture	·295
Total	99·859

It is probable that the saltpetre has been produced by the action on the minerals of the sandstone of acids derived through the nitrification of the animal refuse. It is difficult to account for the large amount of potash compared with the insignificant proportion of soda and lime. Perhaps the microcline and orthoclase felspars were more easily attacked by the acids than the plagioclase felspar. The magnesium salts have probably been derived from the alteration of the mica, which is usually present in the sandstone in small quantity.

Farther down the Waschbank River, on the farm Danebury, the Cave sandstone becomes soft at the top, and passes into crumbly mudstone, pale blue or pinkish-red in colour, but occasionally brilliantly red. Followed round to Montagu Hill, two thin upper beds of sandstone, previously separated by lavas, now unite with the lowest bed to form a thick mass of sandstone yellow at both top and bottom, with blue-pink mudstone in the middle.

On Ellangowan, and thence to the Kraai River, the Cave sandstone is thin, and has a dip of from three to five degrees to the east.

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At Abbot's Inn and Halcyo (Aliwal North) the sandstone splits eastwards, the main bed dipping down beneath the river, while the upper one crops out nearly horizontally on either bank. (See fig. 5.)

There are small undulations in the strata, and at six points on the Kraai River inliers of the main bed occur, before it finally emerges from below the Volcanic beds (on Lilliput, Barkly East).

The outliers of Cave sandstone near Flaauw Kraal (Wodehouse), Kraai River Poort (Aliwal North), etc., have been already mentioned in the description of the Red beds. The main bed of Cave sandstone forms cliffs on the left bank of the Karnmelk Spruit; a little below the hotel the river has cut a remarkably narrow and deep gorge through the sandstone into the Red beds.

Near the police camp the sandstone does not exceed 50 feet, but it thickens rapidly to the north, west, and east, being usually from 150 to 200 feet, but the upper portion, or at least a portion near the top, is composed of a pale bluish mudstone. Towards the north-west, where the main road to Lady Grey turns to the north-east, there is a small outlier of the sandstone. Regular jointing has been developed in the rock, which turns a precipitous columnar face towards the north-west.

On Bamboes Kloof, close to Lady Grey, the sandstone contains very small irregular strings and spheroidal patches of coaly material. Fibrous gypsum occurs, filling small cracks and fissures in the bed.

Behind Lady Grey the Cave sandstone has a thickness of from 300 to 350 feet, and is massive below, but softer and well bedded in its upper half.

The rock is yellowish in colour, and crowded with small whitish patches from an eighth to a quarter of an inch in diameter, giving it a mottled appearance.

In the gorge immediately behind the town there is a large cave in the sandstone. The floor is covered with a breccia of fragments of the sandstone, cemented with carbonate of lime. The calcareous matter is present in large quantity, and the purer parts of the deposit are burnt and used for making mortar. This "drip-kalk," as the farmers call it, has either been produced from the decomposition of plagioclase felspar in the sandstone, or else has come from the lavas above, by percolation through the porous sandstone. Higher up, in the midst of the lavas, is a thin bed of sandstone, which can be traced at intervals along the steep mountain sides into the Herschel district.

The Volcanic rocks form peaks around Lady Grey, which rise to over 8,000 feet above sea-level. The material consists of compact and vesicular lavas, and occasionally pipe amygdaloid. No ash or tuff was noticed anywhere interbedded with the lavas.

In Herschel the Cave sandstone extends all along the northern face of the Wittebergen to a point a little east of Lundean's Nek, near the source of the Telle River.

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The mountain slopes are cut into a series of steep kloofs by the streams which flow down towards the Orange River. Nearly all the streams on being followed upwards towards their sources are found to branch to right and left, running up into a number of narrow gorges, diverging like the fingers of one's hand. The spurs separating these gorges are formed of the upper portion of the Stormberg series.

One of the best examples is the head of the Sterk Spruit, above Josanna's Hoek. The outcrop of the Cave sandstone is therefore very irregular in plan. From a point a little south-east of Herschel to a point just north of the peak Snowdon, the Cave sandstone tends to occur in two or more bands parted by lavas. Further to the east it usually forms one single bed.

At the head of the Bamboes Spruit there is a long spur, on which no less than four beds of sandstone are seen alternating with lavas, while considerably higher up the mountain side is a fifth.

At the head of the stream flowing down through Bensonvale is a fine semi-circular cliff of bedded lavas; below it the Cave sandstone is very thin.

Around Majuba Nek the Cave sandstone is from 20 oto 250 feet in thickness. In places it is a massive bed from base to summit, well seen in an outlier about two miles south of the store on the nek. At other places it is bedded in the middle, usually a little nearer the summit—for example, Josanna's Hoek, head of Krom Spruit, a point about four miles south of Majuba Nek, etc.

Between Majuba Nek and Dulcie's Nek there is a lofty mountainous ridge, rising to an altitude of about 8,000 feet above sea-level.

By reference to the map, it will be seen what an irregularly-shaped figure the boundaries of the Cave sandstone and Volcanic beds form in plan.

At a point about three miles north of Majuba Nek, the lavas apparently rest directly upon the Red beds. East of Dulcie's Nek there is a thin bed of sandstone at some distance above the main bed. On the north side of a large outlier between Dulcie's Nek and Palmietfontein the Cave sandstone is parted for a short distance by a lenticular bed of lava. To the north-west of Dulcie's Nek the ridges are capped with sandstone and lavas; the former being thin in places and sometimes entirely absent. Above Palmietfontein, the Telle River runs between cliffs of Cave sandstone from 200 to 250 feet in thickness. I am informed by the Rev. D. F. Ellenberger, of the Masitisi Mission Station, that at a point close to the Telle River, four miles from Masitisi, many fossil fishes were obtained from the sandstone. These fish remains, I believe, have been presented to the museum at Maseru. At Masitisi there are many trunks of trees, now silicified, derived from the bed of Cave sandstone which forms a cliff behind the mission station.

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From Seaka Drift,, as far as one can see to the north-east, the banks of the Orange River are bordered with cliffs, edged with Cave sandstone, and topped wit Volcanic rocks.

Around Moyena, the Cave sandstone is faulted in several places, the fault faces being separated by dolerite dykes. Moyena itself is perched up on a ridge of Cave sandstone, and has an altitude of about 5,800 feet above sea-level. The sandstone is from 150 to 200 feet thick. Just behind the village there rises a low hill of black andesitic lavas, with thin interbedded sandstones, the whole attaining a height of about 300 feet.

In thin section (1222) of the lava the pyroxene proves to be the orthorhombic variety enstatite occurring as phenocrysts in the groundmass or intergrown with the felspar. The latter is a rather basic variety of andesine, and usually tends to form aggregates, in which the enstatite and a part of the glass are included. The groundmass is typically andesite, with microlites of felspar and enstatite, and crystals of magnetite with a deep-brown glass. An estimation of the silica in the rock, kindly made by Mr. J. Lewis, of the Government Analytical Laboratory, gave a result of 58·4 per cent. The specific gravity of the lava was 2·720. The rock thus belongs to the group of the pyroxene-andesites.

The top of the beds on either side of the Orange River is usually towards the latter, and the river consequently runs in a shallow syncline.

Up the Telle River cliffs of Cave sandstone occur almost continuously along its right bank; on the left bank there are occasional outliers. Between the Telle River and Lundean's Nek there is a large area covered by Cave sandstone, a plateau, cut into by streams running northward from the nek.

The country both to east and west is extremely rugged, the bedded lavas forming precipitous faces on either side of the narrow valleys, *e.g.*, the Dilli-Dilli and Zinxgondo Rivers. On the north side of the Telle River to the north-east of Lundean's Nek there are nearly vertical cliffs of Volcanic beds rising for about a thousand feet, on the faces of which the bedding of the lavas is clearly marked. Where the road up to the nek from the Telle River crosses from the Red beds to the Cave sandstone, at the top of the series of zig-zags, there is a slight unconformity between the lavas and the sandstone. Both dip rapidly to the north, but in a small outlier, to the south of which the road pass, the lava is seen to rest upon an eroded surface of Cave sandstone. Higher up the road a bed of volcanic ash rests upon the sandstone and on the nek itself attains a thickness of about sixty feet. The nek is a narrow opening in the mountains, the lavas rising rapidly on both sides to a considerable height. The altitude of the pass is about 7,300 feet above the sea, and in consequence the police camp there is the highest in the Colony.

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Owing to a slight bend in the valley on the Barkly side, the view in that direction is limited to a few miles, but towards the north-west a considerable extent of country is commanded, and the Mekaling mountains, in Basutoland, beyond the Orange River, are visible.

The thickness of the bed of Cave sandstone as it rises up from the north to Lundean's Nek increases rapidly, so that on Glen Lyon (in Barkly East) it must be over 500 feet thick. The lower slopes of the valleys are smooth, owing to the soft nature of the sandstone, but above come precipitous cliffs of lava, as, for example, on Edgehill and Funnystone.

On the last-mentioned farm there was found in the sandstone a small fossil crocodile, which has been presented to the Museum by the finder, Mr. Isted. This Dr. Broom has named *Notochampsa istedana* (Broom),†† and is closely allied to the crocodile found at Eaglescrag on a slightly lower horizon.

On Wartrail and Glencoe the Cave sandstone is not more than 350 feet thick, and contains reddish bands near its base. On Glencoe there is a very large cave, with a double entrance in the cliff on the bank of the river. The frontage is about one hundred yards, the roof being supported by a large pillar of sandstone at the entrance.

Smaller caves are not infrequent in the neighbourhood, and Bushman paintings are common both in them and on the cliffs which occasionally overhang the streams.

The Cave sandstone hereabouts is always overlain by a bed of purple or green volcanic ash, about eighty feet thick. The ash also occurs on the east side of the Joachim Spruit, towards the north-east and south-east, but on Bidstone and Bonnyvale the lavas rest directly upon the sandstone.

On Glenfillan and Holderness a bed of lava intervenes between the sandstone and the bed of ash, while the latter in some places contains such a large proportion of siliceous sedimentary material as to convert it into a sandstone.

The lavas at Holderness are full of zeolitic minerals. Mr. R. S. N. Orpen gave me a slab, taken from a fissure in the lavas, covered with small tabular crystals of creamy white stilbite. Large quartz geodes are very abundant.

The road from Holderness to Belmore just at the commencement of the long descent, passes between the two northerly beacons of the farm Moshesh's Ford.

The westerly beacon is built on a little truncated conical hill, and on its south side there is a good section from the Red beds

†† Geol. Mag. Dec. V., Vol. I., No. 12, p. 582, 1904.
Dr. Broom reports that the specimen consists of the "cast of the Upper cranial bones and of most of the dorsal scutes with imperfect remains of the limbs. It is an Amphicœlian Crocodile whose nearest affinity seems to be *Pelagosaurus*. From the structure of the skull it seems probable that it a somewhat degenerate type descended from a Pelagosaurus-like ancestor." (see also p. 100).

in the Kraai River up to the ash-bed. The section shows at least 500 feet of Cave sandstone, with a low dip towards the river. This is overlain by a bed of lava about fifty feet thick, the sandstone at the contact being altered to quartzite. The ash bed is about 100 feet thick, the upper part passing into white sandstone. The bed forms a cap to the hill, and in places slightly overhangs.

On the other side of the road there is a large dome-shaped hill, at the foot of which the same ash bed crops out. A very interesting section is exposed in the road-cutting, exhibiting the passage of the Cave sandstone into ash.

The sandstone contains numerous masses of vesicular lava of rather irregular shape, and varying in size from small fragments up to blocks three or four feet across. The peculiar feature about these inclusions is that their lower surfaces consist of pipe amygdaloid, the pipes being arranged normally to the lower surfaces of the blocks. In no case was pipe amygdaloid found on the sides or upper surfaces. This bed passes gradually into ash, with blocks of sandstone, lava, etc. The large volcano of Belmore occurs about half a mile to the south, and it is probable that during the deposition of the sandstone large masses of molten material were ejected, and their lower surfaces became partially embedded in the still-soft sediment.

Steam would be generated below the ejected mass, and the pipe amygdules would thus be formed. The ash-bed stretches away from this point along the mountain face overlooking the Bel River into the gorge known as Martin's Hoek; apparently dying out on the farm Longholm. Above this ash-bed there occurs a second, but it is only found on the upper part of the dome-shaped hill already mentioned. On Moshesh's Ford, about a mile south of the farmhouse, the Cave sandstone at a horizon a little below the base of the lavas contains a few fragments of carbonised wood. The occurrence is only local, and none of the specimens obtained are identifiable, but several bear a faint resemblance to impressions of *Thinnfeldia.*

On the south-west corner of the same farm there is a peculiar mass of columnar dolerite cutting through both Cave sandstone and the thin capping of Volcanic beds. The sandstone, which is pale bluish in colour, is baked to a quartzite for a distance of about four feet from the dolerite, and is beautifully columnar, the columns being straight, waved, or curved, and though many inches in length, are very small in cross-section, usually from half an inch to an inch and a half in diameter.

The intrusive dyke runs northwards for a couple of miles, crossing the Kraai River, and joining up with the great vent at Belmore, and has very probably been formed during one of the eruptions of the volcano. It is, I think, one of the very few dykes in this part of the country which have been intruded during the eruptions of the Stormberg lavas.

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All the other dykes are due apparently to a later phase of igneous activity, and belong to the group of the Karroo dolerites. The specific gravity of the rock, 2·828, which is much lower than that of the normal Karroo dolerite dykes, is identical with that of many of the compact lavas. In thin section (1211), too, the rock shows a structure that is typical of the latter. The dolerite contains porphyritic crystals of plagioclase, often zoned, with abundant enclosures of glass, stone, and augite granules arranged parallel to the faces of the crystals. Olivine occurs, altered to serpentine and calcite. The groundmass consists of a plexus of felspar laths and prisms and granules of augite, with interstitial greenish glass crowded with dusty material and crystals of ilmenite. In some parts of the slide the felspar and augite occur intergrown, but usually granules of the latter surround the laths of felspar. The augite tends to build long prisms, which are often arranged parallel to one another. In many places these prisms are bent at an angle, indicating movement of the igneous material just before its consolidation.

Around Moshesh's Ford the Cave sandstone is pale bluish in colour near the middle of the bed, and is often spotted or ringed with dark material. On Steepside, overlooking the Bel River, there are reddish bands in the sandstone.

The ridge separating the Bel River from the Bok Spruit is a flattish anticline of Cave sandstone, along the crest of which several areas of volcanic beds remain as outliers. The largest of these lies a little to the south-east of Belmore, and forms an elevation, terminating in a sharp ridge rising about a thousand feet above the valley.

The lava immediately overlying the Cave sandstone is a coarse-grained holocrystalline rock, with a specific gravity of 2·887, the sedimentary rock at the contact being baked to a white quartzite to a depth of about a foot.

In thin section (1197) the rock shows laths and prisms of plagioclase felspar; a rather basic variety of labradorite. The crystals are sometimes porphyritic, and show zoning. One good example of such a crystal has a core of very basic felspar, surrounded by a shell of a more acid variety. This is followed in turn by a second shell of basic felspar a little more acid than the first, the whole being enclosed by felspar of a distinctly acid type. Olivine occurs in large grains, but mostly altered to serpentine. Augite is present in the form of granules, which have crystallised before the felspar, and which enclose large plates of ilmenite, usually appearing in section as opaque laths.

A later growth of felspar, with a small amount of quartz, fills up spaces between the earlier formed minerals, and contains small prisms of apatite and crystals of iron ores.

Above this bed of dolerite come vesicular and compact lavas, until at a height of about 400 feet above the sandstone a bed of

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volcanic ash appears, evidently the same as the lower one described north of the Belmore volcano.

The ash is well bedded, the flattish fragments included being usually arranged with their broad faces lying in a horizontal direction. Large blocks of material are commonly collected together in certain points of the ash-bed, and arranged in horizontal layers. The ash is usually brick red in colour, with abundant fragments of lava, now very much decomposed and altered to yellowish areas of chlorite, serpentine, and zeolite. Some parts of the ash are greyish blue, and the divisional line with the red ash is very sharp. The boundary of the red variety is so irregular in outline that it represents very probably ash which has been much weathered, the blue being the unaltered material.

The ash passes upwards into pink sandstone, the total thickness of the bed of fragmental material being about one hundred feet. It is succeeded by several hundred feet of lavas. Farther eastward along this same ridge the ash bed is replaced by yellow-white sandstone, with occasional layers of fragmental material.

It is evident that this bed marks a period during which there was a temporary cessation of lava flows, sediment only being then deposited. Around the Belmore volcano ejected material would form the greater part of the bed, but farther east, away from the vent, sediment would be laid down in comparative purity, and hence east of Clefthill and beyond Rhodes we find a thin bed of pure sandstone.

At Kinmel, east of Rhodes, this bed is usually only a few feet thick, and occurring in between the lavas, has been baked to a white quartzite. Mr. Van Wyk, the owner of the farm, obtained a small amount of coaly material from this quartzite, which led to much unprofitable prospecting of the lavas and Cave sandstone.

The village of Rhodes is situated in the valley of the Bel River at an altitude of 6,150 feet above sea-level. Owing to this, and also to the fact that the mountains rise to a considerably greater height and almost encircle it, the winter is usually very severe. The Cave sandstone crops out all along the sides of the valley, but about two and a half miles above Rhodes the sandstone dips north-eastwards below the volcanic beds.

The sandstone is usually white or yellow, but just opposite Rhodes, on the right bank of the river, the central portion has a bright pink colour. Similar red colouring is present in the sandstone in the Bok Spruit, around Achil, Blarney, etc. The colouring is only local and very irregular; when followed laterally it often disappears quite abruptly.

The mountains around Rhodes all rise to an altitude of about 8,300 feet above sea-level. This plateau-like formation is exceptionally well seen on the south side of the Rifle Spruit be-

tween that stream and the Bok Spruit; only now and then is there a rise above the general level. To the north and east this plateau is also developed, but the peaks of the Witteberg Range, Hawk's Head, Benmacdhui, and Tina Head rise at least a thousand feet higher. This plateau, which extends along to the escarpment of the Drakensberg (overlooking Maclear), is everywhere cut into by a ramification of gorges and ravines. Lofty cliffs are frequent, and the streams occasionally form deep waterfalls. One fine example occurs in the Rifle Spruit, on the bridle-path from Rhodes to the Tsitsa Pass.

To return now to Belmore and the Sterk Spruit, we find that there is a syncline, the axis of which crosses the river transversely on the farm Branksome. The Volcanic rocks and Cave sandstones are brought down until the latter disappears, and the river flows in a very deep and narrow winding channel cut in dolerite. This is only for a short distance, and the sandstone reappears, and occurs all the way up the river valley to the Tembu Pass, on the edge of the Drakensberg.

Between Belmore and Melrose there is the same bed of ash as that already described lying in the midst of the lavas, some distance above the Cave sandstone. It is this identical bed which rests directly on the sandstone at Fetcani Glen (north of Belmore). Near Holderness about 50 feet of lavas intervene. It has been already recorded that a little south-east of Belmore this ash-bed is separated from the sandstone by nearly 400 feet of volcanic rocks. Still farther to the south-east this distance increases a little at first, and then diminishes. The same variation is seen on the west side of the Sterk Spruit, and on Broadford the ash again rests on the sandstone. It is evident that we have here a tract in which lava formed the earliest material erupted, but occupying a restricted area. This was followed by a general ejection of fragmental material, which forms the continuous bed of ash, resting in some places directly upon the sandstone and in others upon the first erupted lavas. It is quite probable that the Belmore volcano was the first to become active in this area, and that there was a slight amount of subsidence to the south, between Belmore and Branksome, the syncline in the strata at Branksome being a later earth-movement. South of Melrose the ash bed rests directly upon the Cave sandstone, and is several hundred feet in thickness. It extends up the west of the valley as far as the Barkly Pass; on the east side it is absent between the Tembu Pass and Carrig Bawn, a distance of nearly eight miles, and it is evident that the ash bed dies out towards the east below the lavas. The bed becomes very thick on the boundary of the Elliot division, between the Tembu and the Barkly Passes. It has been described in dealing with the geology of that area.*

* Ann. Rep. Geol. Com., 1903, p.p., 194, 195.

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In the lowest part of the valley between Johnston's Leap and the Tembu Pass small inliers of Red beds occur, as already described.

Narrow dolerite dykes cut through the Cave sandstone, but at no point here were they observed to penetrate the ash and lavas.

In the Long Kloof Valley the Cave sandstone again covers a considerable area, the dip being always down stream at a slightly greater angle than the grade of the river bed. On the right side of the valley the lavas form lofty cliffs, the ash bed being absent to the north-west of Belleville. On the left the sandstone forms the escarpment of the Drakensberg for several miles, as far as Dinorben. The lavas then reappear, but the ash bed is not present.

At Ravensfell there is a narrow valley descending from the east, and up which the Cave sandstone extends. There are fine cliffs of lava on the north side of the valley, and on Redbrook, Rosehill, etc., the basal ash bed is present. On the latter farm there are quite a number of thin dolerite dykes in the sandstone, usually trending a little east of north. On the farm Singleton (or Botel Nek) the valley widens out into an amphitheatre about two miles across, formed of soft rounded and grassy slopes of Cave sandstone, crowned with rudely columnar lavas. On the north there is a gap in the volcanic rocks, and the road passes over a saddle of sandstone at an altitude of about 7,000 feet above sea-level. At least 650 feet of Cave sandstone are exposed from the bed of the river to the base of the ash bed. The nek leads over into a valley running northwards, and uniting with that of the Sterk Spruit. This connection between the valleys of the Long Kloof River and the Sterk Spruit has produced a mountain range Y-shaped in plan, severed from the large tableland further to the north-west.

At Ravensfell there is a very large cave at the side of the hotel, with a frontage of about 150 feet. It is about nine feet high at the entrance and about sixty feet deep. The entrance has been built up, the cave divided into two portions, utilised as a stable and a store-house respectively. A little further down the valley a similar cave has been used as a coach-house.

The sandstone weathers very irregularly. In some places there are smooth rounded slopes, in others the rock projects in rugged masses or forms cliffs intersected by transverse channels. Most of the sandstone is whitish-yellow, with lighter spots, but pinkish varieties are not uncommon.

A little below Ravensfell the ash bed reappears. On the right bank of the river it rests directly upon the sandstone, but on Krom Draai, on the left bank, there is a separating bed of lava. On the farm Prospect the ash bed rests on the Cave sandstone, but is separated from the lavas by a thin white sandstone bed. The Long Kloof River makes several bends hereabouts,

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and the valley is often not more than a couple of hundred yards across. Along the river banks, especially at the bends, are vast quantities of river gravels, composed chiefly of boulders of dolerite and amygdaloid, set in a deep brown earthy material.

From Prospect, a view to the south-west up a lateral valley discloses a ridge known as the Kops Horn, which must attain an altitude of almost 8,000 feet above sea-level. The ridge is flat-topped, being capped with a thick bed of rudely columnar lava, and forms the natural division between the valleys of the Long Kloof River and the Vaal Hoek Spruit. This same bed of lava caps the Tafel Berg to the south, that prominent ridge of the Drakensberg, so well seen from the low-lying country in the Elliot division.

Returning to the description of the Long Kloof, we find that at Cardistown the valley becomes straight, and widens a little. The Cave sandstone forms little cliffs on either bank of the river, and the ash bed above it, which is not more than 50 feet in thickness, rests upon a very irregular surface. The sandstone on this farm is rather different to the usual type of rock met with elsewhere. It is yellow, with salmon-pink spots, and so friable that it was found impossible to procure a well-shaped hand specimen.

At Ryp Fontein, the adjoining farm, the Cave sandstone disappears beneath alluvium and grass-covered land. The ash bed crops out in several places close to the river, and on Middel Fontein covers a large area, disappearing below the lavas at a point on the river bank about three miles from the town of Barkly. The weathering of the lavas and the volcanic ash gives rise to a very rich black clayey soil, which, after heavy rains, causes the roads to be almost impassable.

At Middel Fontein a dolerite dyke of Karroo type from 8 to 15 feet in width crosses the river in a north-north-easterly direction, cutting through ash and lavas. In thin section (1187) the augite, though of later consolidation than the large felspar crystals, is found to be granular instead of ophitic. A later crystallisation of felspar often encloses augite, which then tends to become idiomorphic. Olivine occurs in small quantity, and there is a fair amount of residual glass, deep brown in colour, containing an abundance of microlites and granular material. The specific gravity, 2·931, is a little lower than is usual for this class of rocks, and is probably due to the quantity of glassy base present.

On either side of the Long Kloof Valley, between Ryp Fontein and Barkly, there are occasional beds of ash and ashy material in the lavas, and these by the prominence of siliceous material of detrital origin may pass into sandstone beds.

The most important of the latter is the bed which is quarried just outside the town of Barkly, on its west side. It has a maximum thickness of about 20 feet, but a large amount of building

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material has been obtained from it, though the stone is very inferior in quality. At the base is an apple-green clay, above which come yellowish-green or purple sandstones, commonly mottled, and with ashy bands; false-bedding occurs in places. The lavas below this bed of arenaceous material are traversed by numerous veins of pinkish sandstone and tuff in a most irregular manner.

It is probable that the lavas which cooled beneath the water cracked, the fissures being filled in with sediment and ashy material. At one place there is an exposure of a bed of compact lava about four feet thick, traversed by a vertical vein of sedimentary material about an inch and a half in width. The top and bottom portions of the in-filling material are soft and friable, the central part (about 2 feet 6 inches) has been baked to quartzite. Evidently the lava flow was still hot in the interior when the fissure was formed.

It is general to find these veins, some of which are over a foot in width, in the lavas just below an interbedded sandstone; rarely do they occur above. In many places the outcrop of the sandstone can be traced by means of these veins traversing small detached outcrops of lava. Similar veins of sandstone ramifying through lavas of old Red Sandstone age have been described by Sir A. Geikie from Scotland.*

At Barkly a narrow irregular dyke of amygdaloid, never more than six inches in width, cuts vertically through the lavas, and may be due to a crack filled in with molten material from above.

Of the ash beds there is a very thin, though constant, band, which can be followed all along the spurs of the hills south-west of Barkly from Ryp Fontein to the head of the Witte Krans Spruit. The ash is usually red in colour, and is sometimes very ferruginous.

A very good section of the bed is exposed on the hillside two miles north-west of Barkly. The bed is here six and a half feet thick, and at the base consists of a bright red sandstone. Higher up it passes into a deep red nodular or spotted ash. In thin section (1188) there is a groundmass of angular quartz fragments, containing many lapilli of very vesicular glassy lava, usually of bright yellow colour. The larger lapilli contain inclusions of quartz grains, fragments of grit, and other foreign material.

This ash passes into a hard, fine-grained ferruginous rock, with black bands, along which there is a concentration of grains of magnetite. This rock has suffered baking from the lavas above it, the base of the latter consisting of pipe-amygdaloid.

To the north-east of Barkly the same bed appears at intervals along the hillside. At one point it is 22 feet thick, being mainly composed of a purple-red rock spotted with light blue.

* Ancient Volcanoes of Great Britain. Vol. I. p. 283-4. 1897.

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Leaving the area around the town of Barkly, we must now return to Moshesh's Ford, and describe the rocks westwards along the Kraai River valley.

On the north side the succession is quite normal. From Wartrail to Abo there is always a thin bed of volcanic ash resting directly upon the Cave sandstone. At the beacon common to Ashton, Abo, and Burley the main road crosses a low spur of lavas, from beneath which the volcanic ash is absent.

On Ashton and Burley the Cave sandstone covers a large area, forming rather difficult country, owing to the numerous deep gorges which have been cut into it.

On Ashton the basal ash-bed reappears and rapidly thickens. On Hopetown, up the valley of the Diep Spruit, the ash covers a large area, while on Lauriston and Queensberry it crops out from below the lavas along the river bank. There is a marked westerly dip in the beds along the Diep Spruit, so that on Rosstrevor and Holbrook there is a plateau of volcanic beds stretching westwards.

Along the south side of the Kraai River, westwards from Moshesh's Ford, there are great irregularities in the succession of the rocks.

The area of subsidence which we have already seen is so marked between Belmore and Branksome, stretches westwards as far as Rebels' Glen.

The peculiar variation of sandstone ash and lava on the farms Rebels' Glen and Cloverly will be described later on when dealing with the volcanic neck on the former farm. The ash-bed from Branksome to "The Caves" is always separated from the Cave sandstone by a thickness of several hundred feet of lavas. The pouring out of such a volume of material took place while sediment was being deposited regularly towards the north and east. We thus find that at "The Caves" the Cave sandstone is only 300 feet thick, while about three miles away it is fully 500. The ash-bed on "The Caves" is about 150 feet in thickness, and passes into a sandstone at its summit.

It contains boulders of white quartzite and of a peculiar quartz-felspar conglomerate, the latter being almost identical with the rock called "porphyroid" from the Cango.

It is built up of pebbles of fresh and unaltered felspar and colourless or milky quartz, up to half an inch in size. In thin section (1196) the felspar is seen to consist of orthoclase and microcline, while the groundmass is formed of small grains of quartz, with flakes of muscovite mica, and fragments of garnet and zircon.

The quartz grains, especially in the groundmass, exhibit cataclastic structures, but the shearing of the rock has been inappreciable in comparison with the speciments from the Cango.

The presence of a rock of this nature, evidently ejected from a volcanic neck close at hand, shows that the Karroo system at

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this point is underlain by rocks of Pre-Cape age, some of which least resemble those of the Cango. It is interesting to note that Mr. Schwarz obtained from one of the volcanic necks in Matatiele boulders of a rock identical with the Cango limestone.

On Holbrook and Lilliput the ash-bed rests upon a thin bed of Cave sandstone, while lower down occur several other arenaceous beds parted by lavas, the main band of Cave sandstone being exposed in the bed of the Kraai River.

The evidence in the field points to an intrusion of lava from a fissure, splitting up the upper portion of the Cave sandstone over an area about three miles in diameter. A little below the homestead on Lilliput the dyke is seen cutting through the two lower beds of sandstone, the uppermost sandstone and the bed of ash not being penetrated.

The rock forming the dyke is a dolerite, vesicular in parts, and the igneous material spreads out between the sandstones, baking their under and upper surfaces to white quartzite. The width of the dyke is about sixty feet and its strike a little north of west. From the vesicular nature of the rock it is probable that the outburst took place during or not long after the formation of the ash-bed, so that the thickness of material beneath which it consolidated was not very great.

Coal was stated to have been found in the sandstone close to the dyke, but I could find no evidence of any carbonaceous material, except a few indefinite plant stems. From Holbrook and Lilliput to the junction of the Long Kloof River with the Kraai River the ash-bed and overlying lavas are the only rocks exposed, excepting at the bend in the Kraai on Caerleon, where, owing to a small dome in the strata, the top of the Cave sandstone is exposed for a distance of about half a mile. A thickness of only six feet of sandstone at the most is visible at any point, but the outcrop has furnished all the stone used in the building of the Loch Bridge over the Kraai River, half a mile farther west.

The junction of the sandstone and the ash-bed is very sharp and regular, and the former has been changed at the contact to a quartzite.

The ash-bed extends a distance of about three miles up the narrow gorge of the Long Kloof River, and at the waterfall passes underneath a bed of columnar basalt. The detailed description of this will be found later on, when we are dealing with volcano number 6. A little higher up the river the ash-bed comes to the surface again, and owing to its soft character, forms a triangular patch of ground covered by alluvium. A little above the bridge, on the Barkly East-Belmore road, the ash passes under the dolerite, and there is a rather peculiar section exposed, fig. 2.

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The ash-bed graduates upwards into a sandy shale, sometimes black and carbonaceous. On the left it passes insensibly into a material which is too decomposed for determination, and which may either be an ash or a very altered vesicular lava. It includes masses of lava (B, B), and sandstone or quartzite (A, A). On the right, with the junction sharply defined, is a bed of fine-

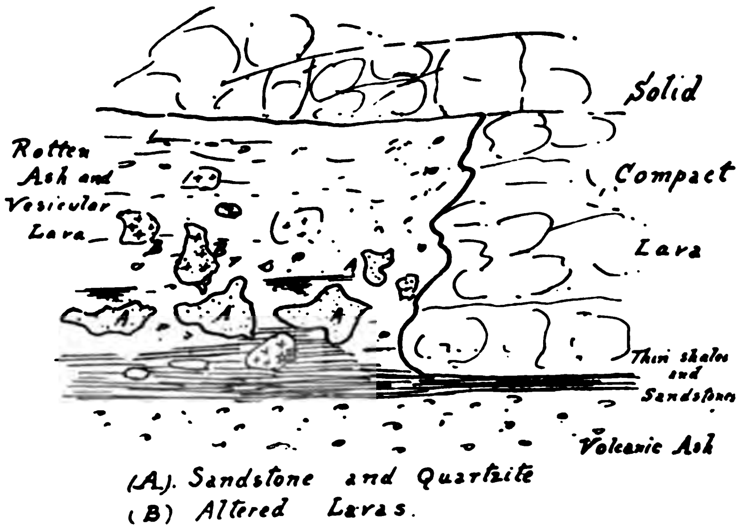

Fig. 2. -In Long Kloof River, ¾ miles east of Barkly East Township.

grained compact lava, terminating abruptly against the bed of decomposed material and overlying it higher up, further to the left.

It shows irregular jointing, and in thin section (1182) shows no uncommon features, excepting a large amount of glassy base.

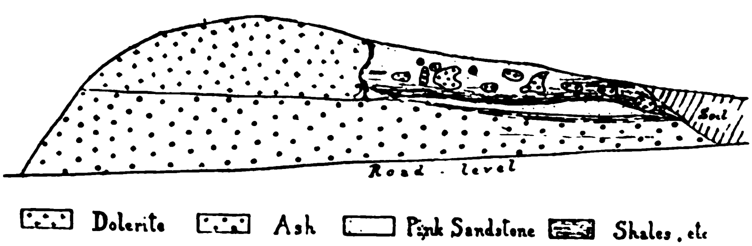

Fig. 3.—Section at east end of bridge crossing the Long Kloof River, one mile from Barkly East. Height of section about fifteen feet.

It is certainly not an intrusion, and a little way down-stream its base is crowded with pipe-amygdales up to ten inches in length.

At the east end of the bridge over the river is a somewhat similar section, very clearly exposed in the road cutting, fig. 3.

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The material on the right above the ash-bed is a pinkish sandstone, sometimes passing into greenish shale, and in which are embedded rounded masses of altered doleritic lava.

The dolerite in the left of the figure belongs to the same sheet as does that in the last figure, and has baked the material in contact with it.

Probably we have here an igneous flow, which was discharged from a volcanic neck with a high velocity. The upper portion of the ash-bed being yet uncompacted, would be cut into, and the channels thus formed filled with dolerite. The proximity of a volcanic neck is indicated by a very coarse agglomerate exposed in a cutting on the road between the bridge and the town of Barkly, the included rounded masses of lava being often several feet in diameter.

Along the Kraai River there occurs a very peculiar bed of finely columnar basalt, the exact relations of which to the neighbouring lava flows is somewhat uncertain.

The bed is fairly well marked, though in a few places the columnar structure is replaced by a rude jointing, and it can be followed on either bank of the river from Holbrook and Lilliput in the east as far as Bulhoek in the west. In some places it seems simply to form one of the normal lava flows; at other places it is manifestly intrusive, and I think that most probably this latter view is the correct one.

On Holbrook and Lilliput it rests directly upon the basal ash-bed, and the columns are arranged in parallel diverging groups in a most irregular manner.

The upper limit of the basalt is never well exposed, but it seems to run very irregularly. Columnar structure is wanting, but the rock now contains large cavities lined with silica, either in the form of agates or quartz geodes. They are sometimes of very large size; one reached a length of fifteen inches, and was eight inches across. It was lined with an inch and a half of milky-white to blue agate, and the interior filled with converging quartz-crystals.

Just above the Loch Bridge over the Kraai River there is a very good section, where the columnar basalt can be seen cutting through a mass of decomposed amygdaloid resting on the surface of the ash-bed. The columns are usually from eight to twelve inches across, and hardly ever show parallelism for more than a few yards. The rock is very compact, and the columns ring under the blow from a hammer. The weathering gives rise to a very thin greyish skin marked with little brown pits.

A little further down the river are fine sections in the road cutting, and the intrusive character of the basalt is certain, but on proceeding further there are no clear sections exposed exhibiting junctions with the overlying beds.

On Witte Krans Spruit there is a very fine exposure of the basalt, the bed being parted along the middle by a horizontal joint plane.

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The columns in the upper and lower portions of the sheet are usually inclined to one another at an angle which decreases until they lie horizontally. Beyond Sevenfontein the basalt is not well seen until after we have crossed the Vaalhoek Spruit, when it crowns the plateau on either bank of the river. On Bulhoek and Draai Hoek the columns are arranged vertically along a distance of several miles. On the opposite bank of the river there is no such regularity in their arrangement. The basalt is here separated from the Cave sandstone by a great thickness of lavas, with occasional sandstone beds.

The intrusive character of the basalt is indicated by the fine columnar structure developed in it; the probable source of the material is, I think, not far from the Loch Bridge, and on the north side, where, as will be shown a little later, there is evidence of the former presence of a volcanic neck.

The sheet of basalt was perhaps injected between two beds of lava, the lower of which had already cooled while the upper was yet hot.

Consequently the base of the basalt sheet is finely columnar, while the upper portion cooled slowly, and may have become to a certain extent incorporated with the upper flow. Wherever the lower bed of lava had not yet cooled the columnar character was undeveloped. It is quite possible ,too, that in some places the basalt may have broken through the covering of lava, and spread itself over the latter.

The petrographical characters show that the rock, even at points remote from one another has essentially the same constitution, and belongs to the Stormberg Volcanic series, and not to the Karoo dolerites.

Three thin sections, (1177) from the Loch Bridge, (1183) from Sevenfontein, and (1192) from "The Falls," show that the rock is composed of plagioclase, felspar, and augite, with a little olivine and residual glass.

The felspar is labradorite in lath-shaped crystals, occasionally porphyritic, enclosing strips of brown glass. The laths tend to form aggregates, surrounded by dark dusty material, round which the augite collects. The latter occurs moulded on, and tends to enclose the felspar in a manner which may be termed sub-ophitic; in (1192) the augite tends to be idiomorphic. A second development of felspar appears to have formed filling spaces between the augite and the first generation of felspar. A small amount of olivine, altered to serpentine, occurs in 1192, grown round some of the felspar laths. There is a fair amount of glassy base from dark brown to green in colour, full of little dark granules. Magnetite is fairly abundant in very small octahedra. Section 1192 differs from the other two in containing small vesicles lined with a green fibrous mineral, perhaps delessite, and filled with chalcedonic silica. The mean density of the rock determined on the hand specimen is 2·834.

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A section (1178) of the very compact upper portion of the basalt from the neighbourhood of the Loch Bridge shows an extremely fine-grained rock, but identical in character with that just described. It contains small vesicles, now filled with agate.

To return now to the description of the beds along the Kraai River, we find that very fine exposures of the basal ash bed occur just east of the Loch Bridge.

The thickness of the bed is about 150 feet. At its base it is dark green, with fragments of black lava and red shale and sandstone, and contains many large angular blocks of lava, sandstone, quartzite, and shale. Higher up it is purple or red in colour, and at the top pale greenish-yellow, and rather fine-grained.

Thin sections (1173-5) prove it to be composed of angular chips of clear quartz, often showing strain shadows and cataclastic structures, fresh orthoclase, and microcline; these minerals evidently having been derived from the disruption of granite and metamorphic rocks. Plagioclase felspar is often abundant, together with augite, rounded olivine, and magnetite, all derived from the lavas. The rock is crowded with angular and rounded fragments of lava, commonly much altered, pre-existing tuff (from the agglomerates of the volcanic necks), grit, sandstone, shale, etc., from the underlying sedimentary rocks.

The groundmass is fine and yellowish in colour, with abundant grains of zircon, occasionally tourmaline, apatite, garnet, and epidote.

Fine sections are exposed for a distance of two miles along the road rising from the Loch Bridge to the plateau on the north. Above the bed of ash comes the sheet of columnar basalt previously mentioned; then occurs a bed of large masses of lava set in an ashy matrix. These masses are often three or four feet across, oval or rounded, vesicular in the interior, with a more compact exterior, and usually show pipe-amygdales rising from their lower surfaces.

The upper surface of this bed is very irregular, and it is overlain by flows of vesicular lava, with bands and lenticles of ash and ashy sandstone, accompanied by intrusive sheets and tongues of columnar basalt, probably from the main sheet below. Higher up we meet with a succession of compact and vesicular lava flows, the beds all having a high dip towards the north and north-west, the whole being covered over with horizontal flows of lava, often very coarse-grained and doleritic. The high dip of the volcanic rocks at this point indicates that they are flows from a vent very close at hand. It is interesting to note the resemblance of some of these beds along the road cutting to those occurring just north of the volcano at Belmore.

The ash-bed can be followed for several miles down the Kraai River. At Witte Krans Spruit, where the Cave sandstone has

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been brought up from below by a dome in the strata, the ash is very thin, and at a point about a mile and a half farther down the river the lavas rest directly upon the sandstone.

The Cave sandstone at Witte Krans Spruit is a very solid fine-grained rock, excellent as a building stone, a great quantity of it having been used in the construction of the bridge over the Long Kloof River, east of Barkly town.

At the junction of the Witte Krans Spruit with the Kraai River there is a large cave in the sandstone. On the north side of the cave is a narrow dolerite dyke cutting through both Cave sandstone and Volcanic beds. At this point the dyke occupies a line of fault, with small downthrow to the north; farther westwards, on Sevenfontein, there is no displacement of the strata along the line of intrusion. In thin section (1193) it shows the usual ophitic structure characteristic of the Karroo dolerites. Its density, 2·94, is a little low, due to the quantity of pale brown glassy base which it contains.

At the bed of the loop in the Kraai River at Sevenfontein the Cave sandstone is again exposed, and is overlain by a lenticular bed of volcanic ash, with a maximum thickness of 140 feet.

On Strydpoort and farther down the river the place of the ash is taken by purple or red-weathering lavas, with occasional beds of sandstone.

The thin bed of sandstone which has been mentioned before as having been quarried just outside Barkly town, can be traced round to Witte Krans Spruit (where it is well exposed on the west side of the gorge), Sevenfontein, and Strydpoort.

Here is thins out, but what is certainly the same bed reappears near Kopje Alyn, and rapidly thickens when followed across Eland's Fontein. Up the Vaal Hoek Spruit the sandstone extends cropping out on either bank at a little distance above the bed of the river. Followed towards the south, the sandstone bed rises at a greater rate than the slope of the river bed, and at Slaap Krans a second bed appears in the lavas below the first one. Finally, on the farm Bamboes Hoek, owing to the rapid rise of the ground towards the head of the valley, both the sandstones disappear beneath the lavas.

The sandstones must die out before reaching the escarpment of the Drakensberg, for when viewed from the south the main bed of Cave sandstone on Radobil (Elliot) is overlain by an unbroken series of Volcanic beds. The sandstone of the Vaal Hoek Valley also crops out in the valley of the Zadelboom, but cannot be traced beyond Clifford. On the spur separating the two valleys is a very thin bed of ash a few hundred feet higher than the sandstone.

This sandstone bed is of great value in determining the geological history of this portion of the Barkly East Division.

It always runs evenly, with a slight northerly dip; nevertheless, the main bed of Cave sandstone and the ash-bed along the

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Kraai River are affected by small folds, producing domes and basins in the strata. And while a little south of Barkly the thin sandstone bed is not more than 100 feet above the main bed of Cave sandstone, the distance increases towards the north and west, until at Strydpoort and Waterfall there are interposed a thickness of fully eight hundred feet of lavas, with thin beds of sandstone.

We have then the clearest evidence of a great zone of subsidence formed during the eruption of the earlier lavas of Barkly East, a zone which extends westward probably as far as the Waschbank River, in Wodehouse.

Similar evidence, though not so distinct. can be obtained from the area north of the Kraai River, between Donnybrook and the Karnmelk Spruit (Aliwal North).

The Vaal Hoek Spruit forms a very deep gorge for about four or five miles above its junction with the Kraai River, and the cliff sections lay bare numerous intercalations of ash and sandstone in the lavas, casting a flood of light upon the conditions which existed towards the close of the Stormberg period.

The following section (fig. 4), taken behind the homestead on the farm Waterfall, shows the alternation of volcanic and sedimentary material.

The lava seen at the very base of the section is at least one hundred feet above the main bed of Cave sandstone, which is not exposed at any point in the bed of the river, while the sandstone bed mentioned previously as running up the valley of the Vaal Hoek Spruit is at a much higher horizon than any in the section.

A study of the beds shows the lenticular character of both sandstones and lavas, the production of pipe-amygdaloids at the base of some of the lava-flows and the presence of rounded portions of lava in the beds of sandstone from small fragments up to masses three feet in diameter.

In the uppermost bed of sandstone are lenticles and beds of ash and ashy material; sometimes the transition is quite gradual, at other times the dividing line is sharp, and inclined at a considerable angle to the planes of bedding.

We find in this section indisputable evidence of the subaqueous nature of the lava flows, when outbursts of molten rock were followed by intervals during which sedimentation went on continuously, while now and again explosive eruptions took place, and masses of lava were ejected from the vents and became embedded in the still soft sediment. The presence of sandstone veins in some of the lava flows, of pipe-amygdales at their bases, and volcanic ash bedded evenly over long distances, all point in the same direction. The dolerite shown in fig. 4, capping the section, is a tough rock, weathering into peculiar blade-like forms, which project out in a jagged mass, and give the hillside a bristling appearance,

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Under the microscope (1194) it proves to a very coarse dolerite, with large augite crystals enclosing the first generation

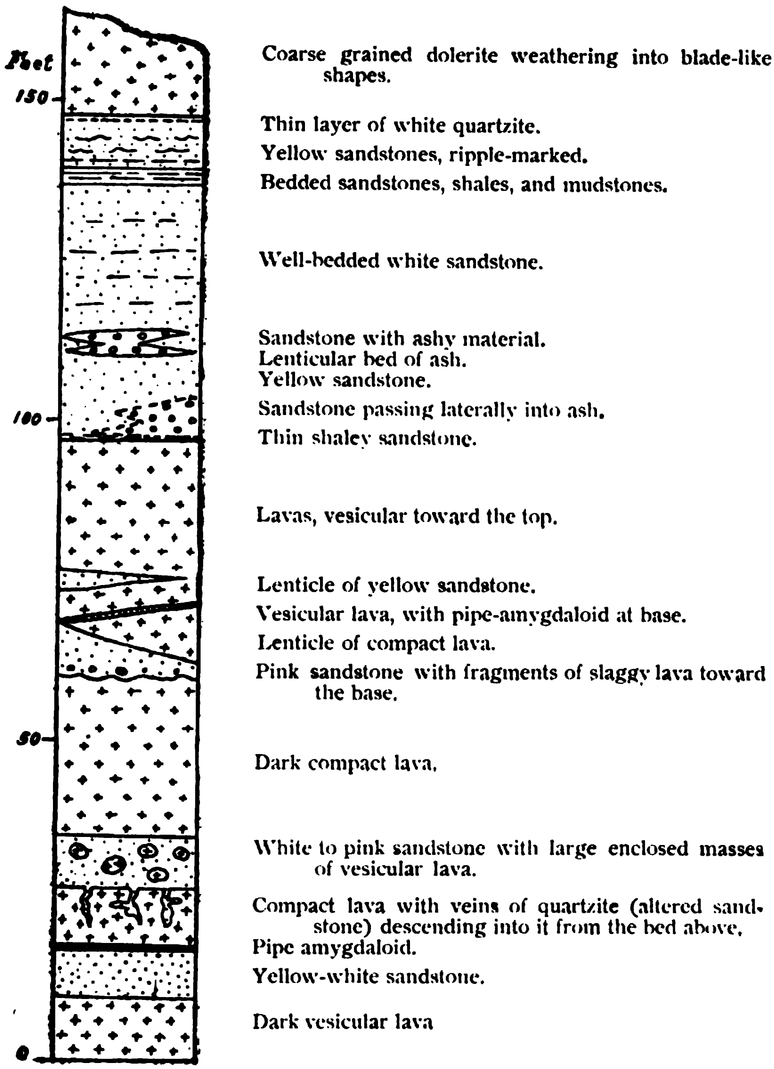

Fig. 4.—Vertical section of beds on farm Waterfall (on Vaal Hoek Spruit) behind the homestead.

of plagioclase felspars ophitically. Olivine was present originally in the rock, but is now converted to bright orange-yellow serpentine. Magnetite is represented by a small number of

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rather large crystals. The specific gravity of the rock is 2·885.

Between Waterfall and Bulhoek the Kraai River flows in a winding gorge, with a depth of from 800 to 1,000 feet, the banks being built up almost solely of lavas capped by a sheet of columnar basalt, which forms a palisade.

On the farm Donnybrook, in a cliff overlooking the river, is a dyke-like mass of soft sandstone, apparently filling a fissure in the lavas. The mass extends down the face of the cliff for a distance of 150 feet, and back from the edge of the same on the top of the plateau for a distance of at least 150 feet.

The sandstone is pale yellow to pinkish in colour, often mottled, and is unbedded, but at the sides it has a slight lamination parallel to the containing walls, and appears to have suffered a small amount of induration. It probably represents a large fissure in the lavas (possibly due to an earthquake), filled in with sedimentary material from above. A little lower down, on Draaihoek and Bulhoek, the main bed of Cave sandstone comes to the surface, and for a distance of about two miles the river flows between cliffs of sandstone, with an average height of from 20 to 25 feet. A dolerite dyke cutting through the Volcanic beds runs from a point south of Clifford and forks; the two portions cross the river on Draaihoek, and extend into the Aliwal North Division.

On Bulhoek, thin beds of sandstone appear again, intercalated between the lava flows. The uppermost of these is probably on about the same horizon as the uppermost sandstone on Waterfall, and from Bulhoek it can be followed round into the Honey Nest Kloof, where it forms thick and conspicuous krantzes.

In the stream a little to the north-east of the homestead on Bulhoek is a very peculiar occurrence of bituminous material in cavities of a doleritic rock.

The dolerite belongs to the Stormberg Volcanic series, but is quite an exceptional rock from a petrological stand-point.

In thin section (1215) it appears to contain, in addition to felspar and augite, large crystals of an orthorhombic pyroxene, either enstatite or bronzite, a mineral which occurs but rarely in the rocks from this area. The orthorhombic pyroxene occurs sometimes in large crystals, with a great tendency towards idiomorphism, sometimes enclosing laths of felspar and sometimes having the latter mineral moulded upon it.

In most cases the monoclinic pyroxene (augite) forms grains attached to the crystals of enstatite, and in some cases completely surrounding them.

The augite is present in large amount; sometimes clear with good cleavage, at other times in irregular granules much resembling olivine. A large part of the mineral has, however, a dark fibrous appearance, due to the commencement of its alteration to diallage. The augite is surrounded by granules of iron-ores.

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The absence of olivine was proved by chemical tests. There are three generations of felspar—the first in small laths prior to the pyroxene, the second in larger porphyritic crystals moulded on the pyroxenes, and sometimes enclosing the earlier felspars. This second generation of plagioclase is more acid than the first, and between crossed nicols a rotation of 50 degrees is occasionally required to cause extinction to pass across the whole crystal. Zoning is not very frequent. The third generation of felspar forms patches, filling up the spaces between crystals, and instead of being clear, is brownish in colour, owing to minute inclusions. In many cases there appears to be hardly any crystallographic boundary between this and the earlier formed felspar, and the wave of extinction between crossed nicols passes steadily from one to the other. It is certain that this must be a very acid type of felspar, possibly orthoclase, for quartz occurs in clear patches intergrown with it. Calcite fills several irregular angular spaces. The specific gravity of the rock is 2·885. The most peculiar feature about this dolerite is the occurrence in it of bituminous tarry material along joints of the rocks and in cavities. In some places the dolerite is veined with opaline and chalcedonic silica, while fissures occur lined with calcite and quartz crystals, and filled in with tarry material. The rock in the vicinity is strongly impregnated with pyrites. A bore-hole was put down in the dolerite for prospecting purposes. At a depth of about 60 feet the rods sank suddenly a distance of about three feet, and just afterwards about six feet through soft material, and when brought up the diamond crown and boring rods were coated with tar. I was informed that small fragments of coal were obtained from the dolerite, which led to the discovery of the tarry material, but perhaps solid bitumen may have been mistaken for coal.

On the opposite side of the Kraai River of the farm Lenham (in Aliwal North) a similar occurrence of tarry and oily matter was discovered, which has led to much prospecting for petroleum.

It is difficult to give any explanation of these occurrences, based only on exposures of rock at the surface. The simplest theory is that there has been a deposition of coaly material along with sandstone and shale in a hollow on the surface of one of the lava-flows, and that a later ejection of molten rock covered up the carbonaceous material and distilled off the hydrocarbons. Against this must be set the fact that nowhere are these sandstones seen to contain any black shale bands or coaly seams.

A second view is that the carbonaceous material is foreign, and has been brought up from below by an eruption, being derived possibly from the Molteno beds. It is important to note that at Belmore pitch and tar occur in the agglomerate filling the great volcano, and it is therefore possible that the original source of the material at Bulhoek and Lenham may have been similar.

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It is interesting to find on the Kraai River, almost midway between the two occurrences, coarse agglomerates, indicating the proximity of a volcanic neck.

On both sides of the Kraai River thin beds of sandstone occur in the lavas, and can often be followed for miles.

The vertical distance between any two beds diminishes as we proceed westwards, and evidently we are getting near the limit of the area of subsidence. Sometimes we even find two beds uniting, as can be seen from fig. 5. The Cave sandstone forms two small inliers in the bed of the river between Lenham and its main outcrop.

There is one feature of the Kraai River valley that needs describing, namely, the great plateau, into which it has cut its deep gorge.

The generalised section, fig. 5, along the river gives a good idea of the plateau and the way in which it has been cut into by stream erosion; the heavy broken line represents the bed of the Kraai River. The plateau extends from Belmore westwards into Aliwal North and Wodehouse, and is usually from 5,900 to 6,100 feet above sea-level. Its width is very variable, for numerous ridges and spurs run out towards the river from the mountain ranges on the north and south. Between the Honey Nest Kloof and the Vaal Hoek Spruit there is a considerable extent of flat ground running up the latter river as far as Eland's Fontein, and up the Zadenboom River to beyond Clifford, rising slightly towards the south.

The town of Barkly East is built on this plateau, and the road thence to Belmore runs along the narrow shelf on the south side of the Kraai River.

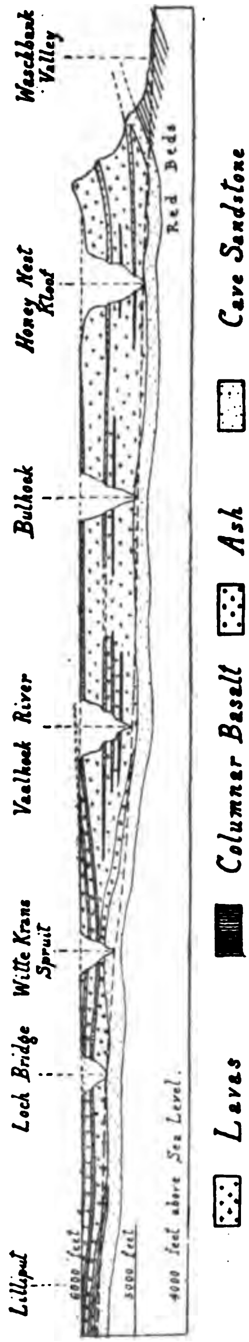

Fig. 5.—Generalised section along the Kraai River Valley. The level of the river-bed is shown by the heavy broken line. Length of section about 26 miles.

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On the north bank there is a large area of flattish country on Burley, Rosstrevor, Glen Almond, Donnybrook, and into Aliwal North, where a portion of it has received the appropriate name of "The Plains."

The two small conical hills known as Great and Little Drizzly Hill respectively form the only breaks in the sky-line. Further westward the strata gradually rise, but the plateau maintains its general level, and the numerous flat-topped outliers of Cave sandstone at the junction of the Kraai River with the Karnmelk and Holle Spruits testify to the former extension of this plateau.

Even in Wodehouse there are great areas of high ground, usually composed of Red beds, but with occasional cappings of Cave sandstone, and it is evident that the plateau extended up to the present watershed in the south, only denudation and erosion have in many places almost obliterated the former features.

It is probable that the plateau extended only as far as a line drawn from Dordrecht to Jamestown, for to the south-west we have again ground rising much above 6,000 feet.

This plateau is really an old plain of river-erosion, formed at a time before the Drakensberg and Basutoland area had been raised to its present position. The Kraai River and its tributaries meandered over a gently sloping plain, vertical erosion having been replaced almost entirely by lateral erosion. A similar plain existed in south-western Basutoland, also at an elevation of about nearly 6,000 feet, over which the Orange River flowed. Owing to a considerable elevation of the earth's crust, the inclination of the river channels was increased; they commenced to cut downward rapidly, and their old winding courses are perpetuated in the deep crooked gorges which remain at the present day.

In the same way the tributaries of the Kraai River, the Bel River, Bok Spruit, Sterk Spruit, etc., flowed over a plain of river-erosion, now situated at an altitude of over 8,000 feet above sea-level. Reference was made to this plateau when the formation around Rhodes was being described, and owing to elevation of the district, the plain was cut into to a depth of about 2,000 feet. Further back than this we cannot go with certainty in this area, but it is quite possible that in Basutoland traces of still higher plateaux may still exist.

VI. Petrography of the Lavas.

The lavas in this area are usually doleritic or basaltic in character, but from Moyena an andesitic lava was obtained, while andesite forms a large portion of the plug in the great volcano at Belmore. Coarsely crystalline rocks are not very common, while coarsely porphyritic types are unrepresented. From coarse rocks we have all gradations to rocks with a flinty appearance.

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The greater part of the lavas are amygdaloidal, the vesicular cavities being occupied by quartz, chlorite, calcite, or zeolites; very rarely are the cavities empty. Ropy and scoriaceous lavas are of not very frequent occurrence; Witte Krans Spruit is one good locality. On the farm Morgenzon, about three miles north-north-west of Clifford, a surface of ropy lava is exposed along the east face of a lofty ridge for a distance of at least half a mile. The surface has numerous ridges, three to six inches from crest to crest, and they are parallel over small areas only. More commonly the surfaces of the lava flows are smooth, very seldom do they show any pronounced irregularities. No bands of bole or red clay, such as are found in the Tertiary basalts of Antrim or the Deccan traps of India, occur in this area. The red-coloured beds which are found occasionally between the lava flows are formed of a mixture in varying proportions of volcanic ash and finely divided sedimentary material, and are never due to the decomposition of lava *in situ*. This is confirmatory evidence that the volcanic beds, or, at least, the lower portion of them, were not sub-aerial in character.

The thickness of the lava flows is very variable, ranging from a few inches up to fifteen or twenty feet, but the beds are often very regular, and may run for miles. This is most noticeable with the very compact varieties, which exhibit a rude columnar structure. A couple of miles to the east of the town of Barkly there is an extensive plateau capped with a bed of this nature; below it come vesicular and doleritic lavas, which weather readily, and form smooth slopes. The density of the more crystalline lavas is low, from 2·82 to 2·91, and the rocks are more nearly allied to the augite-andesites than to the basalts. Olivine when present occurs in but small quantity, and can never be detected by the eye in a hand-specimen.

The principal constituents of the rocks will now be briefly noticed.

The felspar is in most cases some variety of *labradorite*. Occasionally, as in (1197) from Belmore, it is *bytownite*, while in the basalt filling the neck number 2 in Herschel the felspar is *anorthite*.

Even in the andesites labradorite appears to be the commonest type of felspar.

Twinning is nearly always on the albite law; the pericline type was only seldom observed. The felspar of the first generation usually builds small laths, in which glass inclusions are occasionally present. The porphyritic crystals are often filled with inclusions of glass, augite granules, and crystals of magnetite. A second generation of felspars is nearly always present—a more acid variety, which is often untwinned, and forms irregular patches between the already formed minerals of the rock. Some of these felspar areas give a wave of extinction through a very large angle, and must have a great range in composition, pro-

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bably from labradorite or andesine to albite. In a few sections quartz was present intergrown with a felspar, possibly orthoclase. Being the last products of consolidation (except when the rock is glassy), this felspar has a dusty appearance, due to minute microlitic and granular inclusions.

The *augite* occurs either in granules packed into the interspaces between the felspars or in little sub-ophitic patches partially enwrapping them; only exceptionally are large ophitic crystals developed. In the more glassy rocks the augite tends to be idiomorphic. Twinning on the orthopinacoid is occasional.

The augite is green in colour, but is pale or nearly colourless in sections.

The commonest alteration is to a chloritic mineral, and calcite is sometimes produced as well. A diallagic type of alteration is present in the augite in (1215). In (1199), from Belmore, the augite is partly or even completely altered to an almost opaque mass of ferric oxide, giving the rock a dark purple colour.

A *rhombic pyroxene*, probably enstatite, is present in large crystals in 1215 (from Bullhoek), along with augite. In a section (1176) from a boulder at the base of the ash-bed, near the Loch Bridge, there are, in addition to large ophitic plates of augite, green chloritic pseudomorphs of some mineral enclosing felspar, which may perhaps have been bronzite or hypersthene. In the andesites from Moyena and the Belmore volcano enstatite is the only pyroxenic mineral present. The enstatite is usually in well-formed crystals, with long prismatic outlines, but sometimes in granules, having the same relation to the felspar as augite usually has. The mineral is colourless, and not pleochroic.

The *olivine* when present occurs usually as rounded or corroded grains, but is sometimes idiomorphic. Most commonly it is party or wholly altered to serpentine, pale greenish to dark green in colour. In section (1194) a bright orange yellow variety of serpentine occurs, however. In the more altered rocks there is much carbonate along with the serpentine.

The *iron-ores* are chiefly magnetite, but in some slides the long lath-shaped sections show the mineral to be ilmenite.

A small amount of glassy base is present in most of the lavas, and is a prominent characteristic of the andesites. It varies in tint from nearly colourless to deep brown, but is occasionally green. It is usually crowded with microlites of augite and felspar with granules and crystals of iron-ores.

With regard to the micro-structure of the lavas, we find that, excluding the andesites, the two principal types are the granulitic and the ophitic. The latter is not so well represented in this area as in Matatiele, but a type which may be termed sub-ophitic is rather common. It is probable that the ophitic plates of augite have either been broken up or have been prevented from being formed by motion in the lava during its crystallisation. In some of the lavas, either within a volcanic neck (num-

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ber 6, Barkly East; number 15, Herschel), or very close to it, the augite is in extremely minute granules, showing that this view is probably the correct one. Sometimes the augite and felspar occur intergrown, and we find aggregates showing a radial structure, approaching a micropegmatite in character. This is not confined to the rocks containing monoclinic pyroxene, but is also well developed in some of the enstatite-andesites.

Fluidal structures are not commonly found in the basic lavas, but all the andesites, and especially those from the Belmore volcano, exhibit it finely. Perlitic structure is present in some of these glassy rocks.

The great bulk of the lavas are vesicular, the cavities being in nearly all cases filled in with secondary minerals. It is very probable that this infilling took place very soon after the outpouring the lavas, for Dunn states that in the Stormberg area some of the agates in the lavas have been broken across and recemented, showing subsequent differential motion in the igneous rock.

The minerals filling the cavities have probably been derived from the constituents of the lavas, and the effects may be due to the action of the water of volcanic origin held in the vesicles of the lavas themselves.

The alteration of the lavas and the concurrent infilling of their cavities must have begun as soon as the lavas had cooled below a certain point. In some cases there has been a leaching out of a part of the rock. In slide 1198 there are large cavities, into which crystals of felspar and augite project, and which are now occupied with nearly colourless radiating zeolite. Probably these spaces were originally filled with glass. It is easy to account for the zeolites, chlorite, and calcite in the lavas, but the silica forming the agates presents a matter of some difficulty. The columnar basalt of the Kraai River is in its upper portion crowded with agates, often of many pounds in weight, yet the rock is but little altered, and there are no grains of quartz in it which can have been derived from sandstones or tuffs.

Different portions of the same lava flow may have the cavities filled in with different minerals; the same may be true even of a small fragment, while it is not rare to find in a thin slide some vesicles filled with one mineral and others with another. Commonly the cavity is lined with one mineral and the centre filled in with another. The following minerals were noted as either occurring in vesicles or filling joints and druses in the lavas:—Silica, in the form of opal, chalcedony, and quartz, calcite, delessite, scolecite, heulandite, stilbite, and thomsonite.

There is a dark green material filling-up pipe-amygdales in a lava on the south-east corner of The Falls with a radiating crystalline structure. Under the microscope it is found to be composed of a colourless zeolite, perhaps thomsonite, crowded with minute plates of a chloritic mineral arranged in piles and rosettes.

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From Middel Fontein, near Barkly, a rather curious zeolite was obtained filling vesicles in a lava. In physical properties it much resembles the mineral Laubanite from Silesia, *e.g.*, it is snow-white, finely fibrous, and occurs in bundles, with eccentric radiated structure.

The following analysis was kindly made by Mr. J. Lewis, of the Government Analytical Laboratory:—

Silica	45·63
Alumina	26·60
Lime	14·01
Magnesia	·13
Ferrous oxide...	·40
Water	13·21
	99·98

The composition is therefore $CaO.Al_2O_3.3(Si.O_2).\ 3H_2O.$ identical with that of scolecite. The mineral differs from the latter both in physical and optical properties, and may possibly be a new zeolite.

Bituminous or tarry material occurs in a dolerite at Bulhoek (Barkly East).

In the vesicular lavas, the cavities rarely show evidence of having been formed prior to the crystallisation of the felspar laths. More commonly lath-shaped felspars, and in many cases granules and prisms of augite, project into the hollows. This shows that the lavas just as they issued from the volcanic necks consisted of viscous masses crowded with laths of plagioclase felspar, and in many cases too, with crystals of augite.

By the reduction of the pressure the water contained in the lava was set free and the cavities formed. Further crystallisation went on, and the second generation of felspars came into existence.

The vesicles are usually arranged in bands parallel to the surfaces of the lava-flow. In one of the flows, however, just outside the town of Barkly East, a band of vesicles traverses the lava in a vertical plane. Owing to flowing movement in the lava the vesicles assume very curious shapes, and are often drawn out to a great degree, so that the amygdales are much flattened in a horizontal plane. The most remarkable of the vesicular lavas is the pipe-amygdaloid, to which reference has frequently been made in this report. Though occurring abundantly in the Drakensberg, it is not confined to South Africa, and has been recorded in the Deccan traps of India and in Tertiary basalts from Mull.

There can be no doubt, as Dunn first suggested, that the cavities have been formed by steam generated by the flow of the lava over a moist surface, and that they are not, or perhaps only

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in part, due to the water occluded in the molten mass. This is shown by the fact that they invariably occur at the base of a flow where the lava is in contact with an older extrusion or a bed of sandstone or ash. The structure, too, is not confined to beds of lava, for several localities have already been mentioned where ejected masses of lava now embedded in sandstone or ash have pipe-amygdales on their lower surfaces. As the lavas have been erupted sub-aqueously in this area it is reasonable to expect that much steam would be produced during the flow of the molten material under the water.

That the water occluded by the lava may have had no share in the formation of the pipe-amygdales is proved by the occurrence near Barkly of an almost compact lava having these amygdales at its base. As Cohen† pointed out, the condition which was essential to the formation of these amygdales was that the lava should be viscid, and, as we have already seen, most of the flows must have been partially crystallised at the instant of their extrusion.

Commonly there is a thin layer of vesicular lava between the pipes and the base of the flow, while above the pipes may come irregular elongated vesicles, sometimes cylindrical or spherical, apparently modified pipe-amygdales.

The steam generated below the lava formed bubbles in the latter, and if the magma was viscid enough cylindrical hollows were formed. The elongated bubbles tended to rise as a whole, and many may have passed into the higher portion of the flow. Some of them solidified with a rudely cylindrical outline, but as the interior of the flow was probably at a higher temperature, and therefore more mobile, many of the bubbles became irregular or rounded, and now cannot be distinguished from those inherent to the lavas. In fact, it is quite possible that many of the lavas would be compact had it not been for the wet surfaces over which they flowed, the steam bubbles rising up through them and making them vesicular.

Cohen believed that there was no motion in the material while the pipes were being formed, and with the few hand specimens on which he had to base his opinions that may have been the case.

In Barkly East, however, it is found that the vesicles are quite as commonly inclined to the base of the flow as perpendicular.

Deviations of from 10 to 20 degrees are very common, but many specimens show inclinations of from 40 to 60 degrees from the *vertical*. In several places long, almost horizontal, vesicles probably represent pipe-amygdales very much drawn out in the direction of flow. It must be noted that the beds in which these inclined pipes are present do not at any place dip at an angle of

† E. Cohen. Uher einige eigenthümsliehe Melaphyr-Mandelsteine aus Süd-Afrika, p. 7. Nenes Lahrbuch für Mineralogie, 1875.

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more than about one degree, while the inclinations are as frequently opposed to the present dip as in favour of it.

Very often if any one horizon of pipe-amygdaloid is examined it is found that the direction of inclination of the pipes is never constant for any distance, showing irregular movements in the one lava flow.

The pipes are usually from one-quarter to one-third of an inch in diameter, with smooth walls, but larger pipes are sometimes met with having rough irregular walls, and the vesicles are often constricted at points along their length. The pipe-amygdales commonly have a length of from four to six inches, but on Middel Fontein, near Barkly, they attain a length of twelve inches. Horizons of pipe amygdaloid are extremely numerous throughout this area; at one locality a little to the west of the town of Barkly there are over a dozen such bands in a thickness of not more than two hundred feet of rock.

VII. The Volcanic Necks.

There are a very large number, at least sixty, volcanic necks in this area, and in consequence it would be inadvisable to describe each one in detail.

There was insufficient time to examine all the volcanic necks in the Aliwal North division, and hence their description will have to be postponed until the high ground of the Stormbergen has been examined. The visit paid to Telemachus Kop showed that the area around it is extremely complex, and will require careful mapping.

There can be no doubt that the Telemachus Kop group of volcanoes formed one of the dominant centres of eruption at the close of the Stormberg period.

(*i*) *The Volcanoes of Wodehouse.*

Thirteen volcanic necks were recorded from the area examined, but it is very probable that there are still a number yet unknown in the country between Dordrecht and Molteno.

The necks are all filled with white siliceous tuff, very much like Cave sandstone from a distance, and Dunn appears to have mistaken such necks for outliers of Cave sandstone faulted down. Owing to this resemblance, it is likely that such necks may occur penetrating the Cave sandstone, and may then remain unnoticed.

In nearly all the cases in Wodehouse the necks occur near the summits of ridges of Red beds or else partly surrounded by Cave sandstone and partly by Red beds.

Commencing in the south-east, these necks will be briefly described.

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(1). About 11 miles east-north-east from Dordrecht there rises up from an extensive flat of Molteno beds a very peculiar peak, known as Mackay's Kop.

It is a very prominent landmark, being a mass of pale blue tuff, weathered yellow, resembling a gigantic haystack, resting on a mound of sandstone and surrounded by fallen blocks. The actual neck is about 200 yards in diameter.

(2). About half a mile to the north of Mackay's Kop is another smaller neck, rising abruptly from a grass-covered plain. It is about 50 yards in diameter, and the tuff of which it is composed has a rude jointing resembling bedding planes dipping westwards at an angle of about 30 degrees. Close beside it, on the north, is a long east and west dolerite dyke.

(3). About four miles north-west of No. 2, on the east beacon of Vlak Fontein, there is a large tuff neck, oval in outline, and about a quarter of a mile in length.

It rises several hundred feet above the ground on its north side, and is detached from the long ridge of Red beds between Vlak Fontein and Rondavel. The existence of this ridge is due to a great sheet of dolerite dipping south-eastwards.

As a type of the general mode of weathering of tuff necks in the Stormberg area this vent is a good example.

The mass of material shows no trace of bedding planes (such as occur in the Cave sandstone), but is traversed by irregular cracks and joints, while rounded surfaces are developed.

The hill then resembles certain weathered domes of granite. Large irregularly-shaped blocks of tuff break off along joints and strew the ground at the foot of the elevation.

A thin north-east-south-west dyke of dolerite cuts right through the neck.

(4) is a very small tuff neck in the north-west corner of Brak Pan.

(5) is a larger neck on the east corner of Storm Fontein, not very far from No. 4.

(6) is a large neck, at least a quarter of a mile in length, occurring on the summit of a hill of Red beds at the north-western beacon of Labuscagne's Nek.

As it crowns the hill it resembles to a great degree an outlier of Cave sandstone, but the high dip of the strata around it indicates its true nature.

(7) is situated on the farm Waterfal, on the ridge between the Wolve Spruit and the Waschbank River. On the opposite side of the ridge (on Wolve Kop) is a second neck (8), and these two are very similar in shape and situation. Both are cylindrical columns of white tuff occurring at the junction of the Red beds and Cave sandstone, and on opposite sides of the outlier of the latter. Thus the bed of Cave sandstone partly surrounds and protects each of the necks. A dolerite dyke (the same that cuts through No. 3) passes right through the centre of No. 8. It is

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rather a prominent dyke, and can be traced for many miles right across the Waschbank River into Barkly East, penetrating the volcanic beds which form one of the lofty peaks of the Wodehouse-Barkly East boundary.

On the farm Flaauw Kraal (in the extreme north of Wodehouse, close to the Kraai River) there are three volcanic necks, two small ones (9 and 10) in Red beds and a large one (11) partly in Red beds and partly in Cave sandstone.

To the south-west, on Schoorsteen Mantel (" mantle-piece "), a prominent white tuff neck (12) projects from a steep slope of dark Red beds, whence the name of the farm.

The 13th is a pillar of white tuff stained red, in part projecting from the side of a ridge of Red beds on the boundary between the farms Naauw Poort and Koffee Fontein. It is close to Witte Hoogte Siding, and can be clearly seen from the railway between there and Dordrecht Station. This is one of the necks which escaped Mr. Dunn's notice.

(*ii*) *The Volcanoes of Barkly East.*

In Barkly East twenty volcanic necks were noted, but there may be several which were passed over, as the basic agglomerate weathers in much the same way and to the same colour as the amygdaloidal lavas. Many more, too, must exist covered up by the lava flows, and denudation has not proceeded far enough to lay them bare.

The greater number of the necks are found surrounded by Cave sandstone, and the material filling them has nearly always a large proportion of igneous fragments. Siliceous tuffs like those of Wodehouse are practically unrepresented.

Commencing in the west, there are three necks present on the east side of the Honey Nest Kloof, all of them occurring on the outcrop of the thick sandstone band interbedded with volcanic rocks (which has been described earlier in this report).

1. On the farm Buckholt there is a deep gorge leading up from the Honey Nest Kloof, and on either side is the bed of sandstone, about 90 feet thick, overlain by a thick sheet of compact lava, giving rise to a fine waterfall. Above come alternations of vesicular and compact lavas, with occasional lenticular bands of indurated ashy sediments. Just below the waterfall, in the bed of the stream, a mass of fine-grained dolerite is seen cutting through the sandstone and lava, and forming the right bank of the gorge for about 200 yards. At its eastern end the contact with the compact lava is clearly visible, while on the west it is in contact with the sandstone, the latter dipping inwards towards the intrusion at an angle of about five degrees.

At the centre of the section is an outcrop of sandstone surrounded by dolerite, evidently a large inclusion in the neck. The dolerite is medium grained and finely columnar, being quite distinct from any of the lava flows adjacent.

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The limits of the neck cannot be traced towards the north, owing to a thick layer of grass-covered black soil, but there is evidence that it is overlain in this direction by a lava flow. If the evidence in the field has been correctly interpreted, its period of activity must have been ended by the molten lava poured out from a neighbouring volcano.

2. The second neck occurs three miles farther north, on the farm Chilton, at the head of a similar kloof close to the point, where the road commences its steep winding descent into the Honey Nest Kloof.

The bed of sandstone is evidently much disturbed, but as bedding planes are commonly absent, it is only occasionally that the dip of the rock is certainly seen. The neck is composed of a dark green-blue agglomerate almost entirely igneous in composition, only a few fragments of sandstone and quartzite being present. Amygdaloids and compact dolerite lavas form the bulk of the rock.

The area of the neck is uncertain, and the tuff is only exposed for a little distance around the head of the kloof. It is cut through by a coarse-grained doleritic intrusion, Y-shaped in plan, and the river affords a fine section of the rock, with its vertical columns sometimes as much as 30 feet in length.

As the dolerite is traced upwards and outwards it loses its columnar character, and cannot be distinguished from the doleritic lavas in its vicinity, owing to their similarity in weathering. It is, therefore, uncertain whether it penetrates the lavas or whether it is actually connected with them. If, as is very probable, this last is the case, then we have one of the few occurrences where the direct connection between the material filling the vent and the extruded lava can be witnessed.

3. In the next kloof, a little farther north, is an outcrop of purple-blue tuff, crowded with fragments and blocks of volcanic material. The boundaries in this case are also uncertain.

At Lenham, a farm on the Kraai River (but just within the Aliwal North division), there occurs below the farmhouse, on the river's bank, sandstone, bedded lavas, and agglomerate overlain by lavas with thin interbedded sandstones. The agglomerate is penetrated by columnar dolerite, which spreads out in a sheet, seen overlying the Cave sandstone towards the east and cropping out on the banks of the river on the south and south-west. One of the specimens from the agglomerate is a tuff, with a pinkish-white groundmass (containing calcite), with dark greenish black fragments of lava. The length of the exposure is about 100 yards, and the materials appear to be an outburst from a volcano situated on the north side of the river.

A little way up the river (on farm Delta) is a thin bed of hard siliceous ash, which has been much baked by overlying igneous material.

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4 is situated on the farm Eland's Fontein in a bend of the Vaalhoek Spruit, the stream apparently bounding it on two sides. The wall of the pipe is well seen on the north-west side, and consists of bedded lavas and an upper layer of feebly bedded sandstone, but the actual contact is not visible.

The pipe is about 200 yards in diameter, and is filled with coarse agglomerate, boulders of amygdaloid and dolerite, with an occasional block of sandstone, set in a hard quartzitic cement, grey in colour.

There has evidently been a silicification of the mass in the pipe and the agglomerate is extremely hard. In one or two places small quantities of a pitchy mineral were found in crevices associated with calcite and zeolites.

The agglomerate even from a short distance resembles very much the surrounding lavas, and it is probable that there may be more such necks cropping out along the Vaalhoek Spruit.

5. About four miles north-west of Barkly is a deep gorge cutting through the Volcanic beds, and exposing the Cave sandstone, whence the name of the farm, Witte Krans Spruit. In the bed of the stream and apparently surrounded on all sides by Cave sandstone are a few outcrops of tuff, which must belong to a volcanic neck at least 50 yards long.

The southern contact with the Cave sandstone is visible, and the tuff is here almost entirely siliceous in character. It is dark bluish green, containing grains of glassy quartz, fragments of dark sandstone and shale and numerous pieces of red shale and micaceous sandstone, derived evidently from the Red beds. Towards the centre of the vent there are numerous masses of compact and amygdaloidal lava, the spaces between the blocks being often filled with sandstone or shale baked to quartzite or porcellanite. A little south of this neck is seen a bed of volcanic ash resting upon the Cave sandstone, and not more than from 30 to 35 feet thick. Probably it has been composed of material ejected from this vent, for the bed of ash is identical in character with the tuff in the neck.

Immediately above this bed of ash is the peculiar sheet of columnar basalt which has already been noted as occurring along the Kraai River banks for a considerable distance, while a little higher up, not far from the main road, is a peculiar bed of agglomerate. It consists of large rounded masses of dark-coloured lava, often several feet in diameter, set in a groundmass of yellowish decomposed amygdaloid and ashy material. The rounded masses usually show an outer zone of compact rock, while the interior may be vesicular. Spaces between the masses are filled in with ash and irregular ramifying tongues of lava. Evidently the bed represents material ejected from the vent, ash, scoriae, and bombs, the whole being permeated with liquid lava. About 15 feet of the bed is seen (base not exposed), and it is followed by a compact lava flow.

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At the junction of the Witte Krans Spruit with the Kraai River the surface of the ground is strewn with fragments of ropy lava, perhaps from one of the flows issuing from this neck.

6. On the left bank of the Long Kloof River, midway between Barkly and the Kraai River Bridge, is a rather peculiar small neck. The lowest bed visible in the river gorge at this point is the thick basal bed of volcanic ash, the top of the Cave sandstone cropping out in the stream bed a few hundred yards farther down. Above the ash comes a bed of lava, slaggy at the top and overlain by the sheet of columnar basalt referred to previously. The boundary of the neck is not very well defined on the side adjacent to the river, but each end is marked by a nearly semi-circular rim of columnar basalt.

The neck is filled with a rather decomposed material, vesicular in places, and which resembles very much an altered lava. Elsewhere occurs an undoubted tuff, with fragments of shale, quartzite, and igneous material, including numerous masses of scoriaceous lava, mostly rounded, up to 18 inches in diameter, and looking like bombs. The cavities in these masses are sometimes filled with calcite, but more commonly the vesicles are empty, the rock being slaggy, and showing flow structure.

The thin section (1189) shows a very fine-grained glassy rock, with a few porphyritic felspars, but of no great size. The groundmass consists of a dense matted aggregate of felspar microlites, with granules and prisms of augite set in a dark brown, almost opaque, glass. The blow-holes, when not empty, are lined with delessite and calcite.

The bed of lava immediately overlying the basal ash bed is slaggy and scoriaceous near its upper limit, immediately adjoining the neck. About 150 yards away it becomes variable in character, usually fine grained, with minute vesicles, and sometimes more like an agglomerate with veins and masses of tuff between rounded lumps of lava.

This igneous material must have issued from this neck, as under the microscope (1190) it shows a great resemblance to section 1189.

The north-western limit of the vent must now be described; it is very irregular, and not well defined, and apparently it is not the edge of a vertical wall, but the boundary of a horizontal sheet of lava.

Here we have two hypotheses; either the sheet is an overflow from another volcano covering up this vent or more probably it is a flow directly connected with the vent itself.

A little way north of this neck are good exposures along the river bank, showing a lenticular bed of yellow sandstone passing into pink and red ashy sandstone interbedded between lavas. The upper surface of the siliceous bed in contact with the overlying lava flow is often not regular, but forms a series of waves, with a distance of from two to three feet from crest to crest. It

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resembles exactly, only on a larger scale, the ripple marks formed on the sea-shore, and I think that they have been produced by the rapid flow of the lava over a bed of soft uncompacted sediment. The upper surface of the sandstone and sandy tuff has been baked to a hard quartzite to a depth of as much as six inches. The overlying lava is fine grained, with numerous agates from one to three inches in length.

A little further up the river, at a point not quite two miles from Barkly, is an occurrence of agglomeratic material, indicating the presence of a volcanic neck close at hand. The Long Kloof River forms a waterfall over a bed of columnar basalt, due to the undercutting of the basal ash bed beneath it. On the left bank of the river for a space of about 120 feet there is a gap in the columnar basalt, filled in with bedded sandstone and ash and masses of lava.

The ash and sandstone are much disturbed, and are lenticularly and irregularly bedded. In places they are baked to hard quartzite. One of the beds of ash a few feet thick is composed chiefly of igneous material, and though brown in colour and much altered, shows under the microscope abundant fragments of clear fresh felspar. The inclusions in the ash consist chiefly of igneous material, and lumps of slaggy lava are not uncommon. There are also rounded masses of white crystalline limestone, but whether these are nodules due to segregation or foreign blocks is uncertain. The basal bed of ash underlies this mass, while a short distance away from the river are the usual horizontal flows of igneous material. We may then regard the occurrence as being due to an outburst from a volcanic neck situated on the west side of the river; for on the east the bed of columnar basalt runs unbroken.

7. On the road from Barkly to Moshesh's Ford, a deep transverse gorge at Rebel's Glen has to be crossed, made by a stream running northwards into the Kraai River. The road descends on the west side over Volcanic beds, lavas, chiefly doleritic, with a thin bed of ash overlying the Cave sandstone. This ash bed is the same as that seen on the neighbouring farm Lilliput, but is much thinner. The floor of the valley at this point is formed of Cave sandstone.

As the road is followed up the narrow valley, the Cave sandstone is lost sight of, and the ash bed apparently replaces it, while the lavas above run regularly without a break.

Behind the farmhouse, the road passes over coarse agglomerates, and we find here a volcanic neck (see figure 6).

The contact of it with the Cave sandstone is given by a cliff section, about 15 feet high, and apparently the pipe is funnel-shaped.

At the base of section occurs a coarse agglomerate, containing blocks of sedimentary and volanic rock; higher up comes a series of lavas, inter-stratified with ash, and lying nearly horizontally.

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A little way up the stream, close to the road, the contact of the agglomerate with the ash-bed occurs. The area occupied by the neck, as marked on the accompanying map, is only conjectural; on the east the rocks are covered with soil and alluvium; and on the west there are numerous blocks strewing the surface, and weathered either out of the ash bed or the agglomerate.

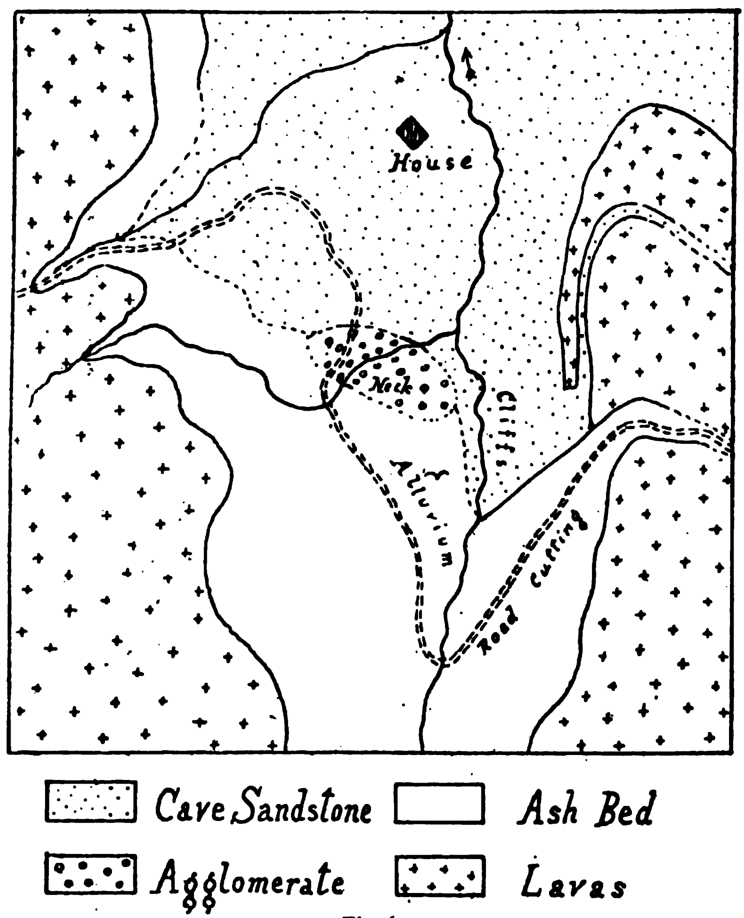

Fig. 6.

Some of these blocks, which are certainly weathered out of the latter, consist of a peculiar brownish or buff quartzitic rock, and are evidently masses of fine-grained silicious tuff, which have suffered baking within the pipe.

The ash bed is well exposed on the west of the road in the small stream which passes across the neck. It is unbedded at the base, but well stratified just below the capping of lavas. In

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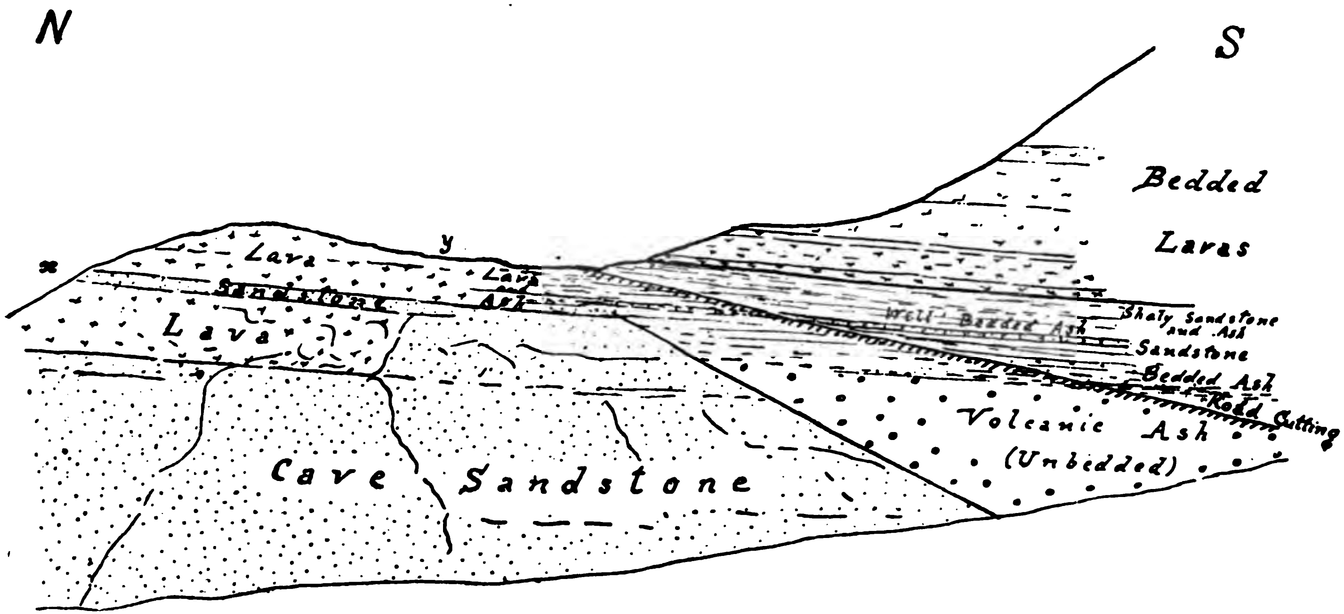

Fig. 7.—Section on river bank, south end of Rebels' Glen (view of east portion of area fig. 6).

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addition to the usual igneous and sedimentary inclusions, it contains boulders of white quartzite, resembling the Table Mountain sandstone or Witteberg quartzite, and coarse grits, derived evidently from the Molteno beds. A peculiar greenish quartzose grit, with portions of roots or stems of trees, was also found; the rock does not resemble any known to occur in the Stormberg series. By far the most interesting section is that visible on the east of the valley, where the road ascends (figure 7). The Cave sandstone, which has a low dip to the south, terminates abruptly as though faulted, and against it lies the ash bed, the plane of contact dipping southwards at an angle of 30 degrees. There is, however, no evidence of faulting both ash and sandstone being undisturbed up to the very line of junction, and there are no slickensides on the sandstone. The angle, too, is rather low for a fault, and in addition, on the west side of the valley, as already remarked, the ash bed to the north is thin and rapidly thickens southwards; how this is due is uncertain, as there are no clear exposures. Furthermore, less than two miles due east of Rebels' Glen, on the farm Cloverly, is a similar occurrence, and the ash bed rapidly thickens from north to south, and covers a great area behind the house, underlain by a bed of sandstone (the same layer as that marked *x* in fig. 7). I think the most probable explanation is that there has been local erosion of the Cave sandstone, and that the ash was deposited in the hollow thus excavated. All along, from Lilliput to "The Caves," we have considerable variations in the beds. Irregular lenticles of sandstone and ash occur in the midst of the lavas. Beds of lava rest upon uneven surfaces of sandstone, and are often lenticular in character.

As an example, we may notice the interbedding of sandstone and lava in the left of fig. 7. The lowest of the lava flows terminates abruptly against sandstone; farther to the east this identical bed of igneous material attains a considerable thickness.

To return to fig. 7. The ash at the base is unbedded with abundant blocks of included material. Near the summit are alternations of sandstone, ash, and ashy sandstone, and the junction with the well-bedded lavas is very distinct. On the north side of the road these beds of sandstone, ash, etc., interdigitate with lava, until finally they are entirely replaced by the latter, *e.g.*, at *y*.

8. In the bed of the Diep Spruit (a tributary of the Kraai River), on the farms Ashton and Rosstrevor, is a volcanic neck, occupied partly by a mass of dolerite and partly by coarse agglomerate.

On the north side the Cave sandstone has a high dip inwards, as much as 25 degrees; but on the east the beds lie almost horizontally. The basal ash bed overlying the Cave sandstone, which towards the north-east is thin, here thickens, and form a marked outcrop below the overlying lavas on the right bank of the river. Bedded ash and lava occur on the south side of the

neck. The dolerite in the neck is displayed where the road from Lundean's Nek descends to the drift, and varies from a fine-grained compact variety to a coarse-grained rock. Scoriaceous slaggy lavas occur on the south, at the top of the ridge overlooking the drift.

Between Wartrail and Moshesh's Ford there are three volcanic necks, not very far apart from one another.

9. The first of these, on Fetcani Glen, is a great funnel-shaped mass of blue-grey tuff and coarse agglomerate.

The Cave sandstone dips in from both east and west at as high an angle as 30 degrees, the disturbance extending for quite a distance from the edge of the pipe. A fine section is to be seen from the main road, at the point where a branch of the Joachim Spruit has cut through the south portion of the neck.

10. The second neck is a fairly large one, and situated in the eastern corner of Glenfillan, at a point where the road crosses the stream coming down from Holderness. On the left bank of the stream hard blue-green tuff, in contact with the Cave sandstone, is exposed in a road cutting. On the right bank of the stream there is also a small exposure of the tuff, but the greater part of the neck is occupied by a plug of rudely columnar dolerite, forming a vast dome, on the hillside.

The north-eastern boundary of the neck is constituted by lavas, with an ash bed, which has probably been derived from this volcano. On the north-west and north there are good exposures along the road cutting, showing thick beds of ash, dark in colour, and weathering spheriodally almost exactly like dolerite.

This ash is overlain by laminated sandstone, and shows that the volcano came into existence at an early period.

Higher up the cutting, tuff is again exposed, with sandstone both above and below it and apparently it thins out rapidly and disappears. Further up the mountain side the sandstone passes into a purplish bedded ash; then follows white sandstone and bedded lavas with a thin ash-bed. On the south side, there is no ash interbedded in the Cave sandstone. The latter dips inwards towards the neck at an angle of 15 degrees.

11. The third neck is a little over a mile higher up the same little stream, on the farm Holderness, and about half a mile below the house.

The neck is filled almost entirely with a hard bluish-grey tuff, in places very fine-grained, and almost like a quartzite, in which are embedded blocks of sandstone, grit, etc. For about 100 yards along the banks of the river this tuff is exposed, and the junction with the Cave sandstone shows the latter dipping inwards towards the vent.

The neck cannot be traced far from the river bed southwards, as it is very difficult to distinguish the weathered tuff from Cave sandstone, while the ground is grass covered. On the north, the

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ground rises rapidly to form the range between Holderness and Bonny Vale, and the lavas apparently overlie the tuff in this direction. No clear section is seen, as there is much covering material fallen from the lava cliffs above.

Under the microscope, the rock proves to be composed of angular and rounded fragments of quartz, with a very fine yellowish cementing material. Little pieces of grit and altered igneous rock are present, and the ground mass contains fragments of felspar and small grains of zircon and epidote.

12. This is but a small neck, about 50 yards in diameter, on the steep north bank of the Kraai River, just within the western boundary of the farm Moshesh's Ford. The river has just cut through its southern wall, and the curve of the latter (Cave sandstone) is broken for a few yards. The neck is filled with a siliceous tuff, very much like a gritty sandstone, built up of small angular fragments of glassy quartz, with here and there a grain of pink felspar.

The tuff contains blocks of sandstone, shale, and lava.

13. One of the largest and the most important volcanoes of the Barkly East division is situated on the north side of the Bel River, where the latter joins with the Sterk Spruit to form the Kraai River. The drift at the junction is known as Moshesh's Ford, but the shorter name of Belmore, from the hotel on the river's bank, has been given to the volcano. The Belmore volcano is nearly three-quarters of a mile in diameter, and as shown in the accompanying sketch (fig. 8), rises to a height of about 700 feet above the river, and forms three smooth domes, united at their bases. The boundary of the vent is fairly well seen, and in outline is rudely elliptical with, in places, a small irregularity in outline. The vent is filled with tuff, penetrated by sills of enstatite-andesite, and dolerite, while the dome-shaped hills are formed of fine-grained columnar enstatite-andesite, the more basic rocks being always of greater age than the more acid. Commencing our description on the west side of the volcano, we find that very fine sections are exposed on the right bank of the Kraai River, where it makes a sharp bend to the west. Here the Cave sandstone forms a very steep slope, and a few hundred feet above the river comes the agglomerate, crowned with columnar andesite. A small mass of very coarse sandy agglomerate projects out from this face of sandstone and probably represents an offshoot of the main mass. Close at hand too, is the dolerite dyke, which crosses the river and cuts through Cave sandstone and lavas south of Moshesh's Ford. It has been described earlier in this report, and probably fills a fissure formed during one of the eruptions of the volcano.

A little farther to the south the main mass of agglomerate sends a tongue into the sandstone, which is about 50 feet wide, and which reaches almost to the river's bank. In the central portion it is almost entirely formed of igneous material, dolerite,

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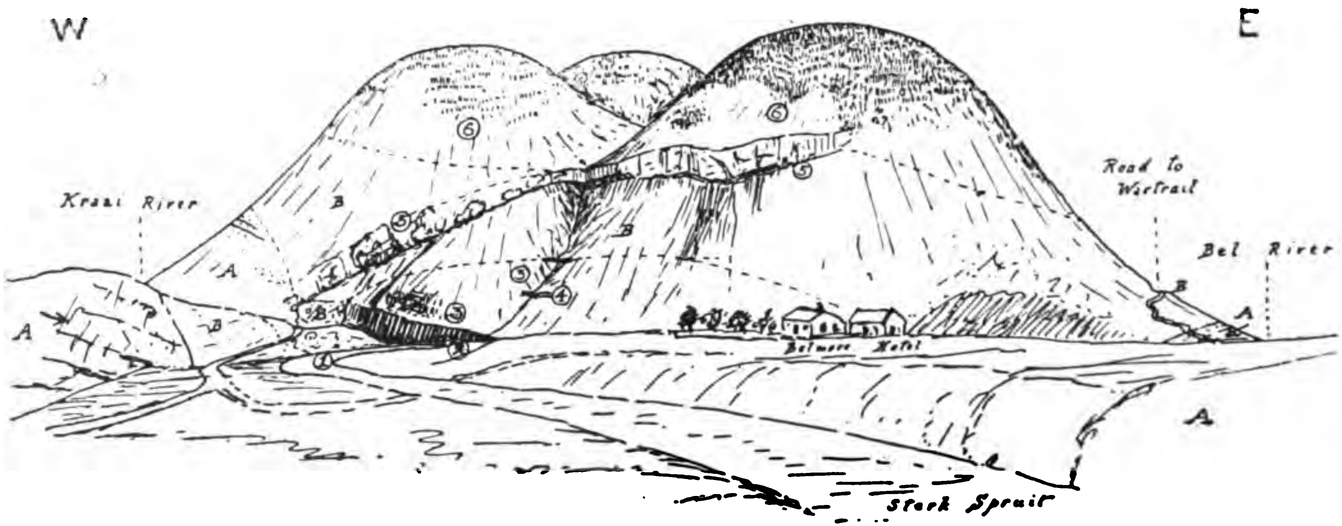

Fig. 8.—Volcanic neck at Belmore, on north side of junction of the Stèrk Spruit and the Bel River, the two then forming the Kraai River A indicates Cave sandstone; B Agglomerate. The numbers attached are referred to in the text.

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amygdaloid, and compact lava; among the inclusions are masses of lava, with layers of pipe-amygdales, evidently fragments torn from the earlier-bedded lavas, as the volcano enlarged its chimney. The amygdales are filled in with zeolites, and it is impossible to say whether the infilling took place within the pipe, or whether it was effected prior to the formation of the agglomerate.

Towards the margins of this tongue-like intrusion, the agglomerate becomes more siliceous ,and in many places passes almost insensibly into the Cave sandstone as owing to the shattering action of the volcano, the latter has been brecciated, and has contributed largely towards the formation of the agglomerate in contact with it. Just opposite the farmhouse on Moshesh's Ford is a very narrow irregular dyke in the sandstone, apparently extending from the volcanic neck. It is filled with a dark spotted rock, which may either be a very altered lava or a very basic fine-grained agglomerate. The boundary of the neck is hidden at this point by soil and blocks of glossy andesite, but close at hand it crosses the Kraai River. On the north bank, the sandstone is brecciated, and the agglomerate so formed is penetrated irregularly by dolerite and is much indurated.

In the angle formed by the junction of the Sterk Spruit with the Kraai River there are good exposures of the south-western boundary of the neck, along the road side (see fig. 8). The Cave sandstone (A) dips inwards at an angle of about 15 degrees; next to it comes pale-bluish siliceous agglomerate (B). The latter is cut and penetrated by a mass of basic material (1), sometimes agglomeratic, and containing masses of sandstone and tuff, and sometimes very compact and doleritic. Close to the river bank this rock contains a small amount of tarry and pitchy material along joints and in cracks.

The boundary of the neck probably runs across the angle formed by the meeting of the Sterk Spruit and the Bel River, but no outcrops are visible, owing to a thick covering of river gravels.

On the north bank of the Bel River the pale blue siliceous agglomerate is again exposed, and the Cave sandstone dips inwards at an angle of about 12 degrees. Immediately behind the hotel there are no exposures, the hillside being thickly strewn with fallen material. At the base of the hill at the junction of the rivers is a sheet of columnar dolerite (2), with a dip to the north-east of about 15 degrees. The columns are very regular, and the intrusion forms a cliff on the bank of the river, in one place about 20 feet high. Toward the west it is seen intrusive in the agglomerate (B). The rock is traversed by numerous concealed joints, so that it is almost impossible to procure a good hand specimen.

In thin section (1207) the rock proves to be an olivine-dolerite, and is rather more basic than the usual volcanic rock. The olivine is present in quantity in the form of granules, but occasionally

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showing good crystal outlines. There is a partial or complete alteration to green serpentine. The augite is pale in colour, and occus sometimes idiomorphic, but usually moulded on the felspar; the ophitic structure is never developed. The felspar is labradorite, and occurs in long laths and prisms. A second generation of more acid plagioclase felspar, later than the augite, fills up spaces between the crystals, and is crowded with granules of augite, crystals of iron ores, and prisms of apatite. Plates of ilmenite occur, showing lath-shaped sections, and have been formed immediately after the olivine. The specific gravity of the rock is high for one of the Volcanic series, namely, 2.913. Above this sheet comes more dolerite (3), which, on weathering, crumples to form a yellow brown sand. It may be part of the lower masses of dolerite, or it may be a separate intrusion.

In thin section (1206) it proves to be likewise an olivine-dolerite, but it is more altered. There are large areas of green serpentine, with a little calcite representing the olivine.

The serpentinous material has forced its way into the cleavages and cracks in the other minerals. Labradorite and augite occur with mutual relations similar to those in section 1207. The second generation of felspar is clear, shows undulating extinction between crossed nicols, and is usually untwinned. The specific gravity is 2.78, but the low value is due to the alteration in the rock. The limits of this doleritic intrusion are uncertain towards the east; in the small stream up the face of the hillside the upper boundary is exposed, and the dolerite cuts through agglomerate greenish to reddish in colour, in which igneous material forms an important proportion.

A little lower down in this stream is a narrow dyke (4) or sill of black glassy andesite, cutting through the dolerite, showing that the more basic rock preceded the more acid.

Running diagonally up the face of the hill is a large sill of glassy andesite (5), with a maximum thickness of about fifteen feet, and having a dip towards the north-west. At many points its intrusive junction with the agglomerate is to be seen, and possibly, too, it may prove later in age than the columnar rock capping the hill.

The rock is dark black in colour, breaks with a conchoidal fracture, and exhibits fine banding and fluidal structures, best seen on weathered surfaces., Some parts of the intrusion, especially that occurring towards the base of the sill, are full of fragments of foreign material derived from the agglomerate, so much so that in places the amount of igneous material is less than that of the inclusions.

Under the microscope (1202), the glassy ground mass is seen to contain crystals of plagioclase and the orthorhombic pyroxene, enstatite. In places the felspar and enstatite have been drawn together, and are ophitically intergrown, followed by a second generation of more acid felspar. The minerals are often ar-

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ranged in the ground mass in parallel bands, with marked orientation. Occasionally the crystals have been twisted round, so as to have their long axes perpendicular to the direction of flow, and then the stream lines in the banded glass form beautiful curves around them.

The specific gravity of the rock is 2.549, and the percentage of silica, kindly determined by Mr. J. Lewis, of the Government Analytical Laboratory, is 61.6. Consequently the rock is an enstatite-andesite of a slightly acid type.

A second section (1203) shows the same minerals plagioclase and enstatite, the latter often in long prisms. The ground mass is a glass, with wavy dark brown and light brown bands, the latter crowded with enstatite microlites. There are foreign inclusions, large quartz and quartzite grains, sometimes showing slight corrosion borders, also small fragments of grit.

A third section (1204) is from a similar glassy rock, but is crowded with foreign inclusions, such as quartz and felspar grains, fragments of grit, sandstone, and shale. The glass is bright yellow to brown in colour, and has perlitic structure finely developed in it.

The rock which crowns the hill, and which is usually columnar, is also an enstatite-andesite, but is usually free from xenolithic inclusions, and is, as a rule, less glassy than the andesite sill below it. A microscope section (1200) of a sample from the west side of the hill shows a very dense glassy groundmass in which are embedded crystals and crystal aggregates of plagioclase and enstatite. The felspar phenocrysts contain abundant enclosures of dark glass, with granules of enstatite in parts. In the groundmass there are bands rather lighter in colour than usual, in which are small fragments of quartz, evidently sand grains picked up by the molten rock.

The specific gravity of the rock is 2·614. Another section (1201), from the west side, shows a somewhat less glassy rock, with a structure that can be termed hyalopilitic. There are aggregates of plagioclase, enstatite and clear brown glass, sometimes with a considerable area, which are embedded in deep brown glass, with abundant microlites of felspar and granules and prisms of enstatite. The felspar and enstatite often form fine radial intergrowths; at other times they build up independent crystals. The specific gravity of the andesite is 2·673.

A third section (1205) was taken from the mass of columnar material on the south side of the hill. The felspar and enstatite have a greater tendency to build up separate crystals, and any aggregates are, therefore, of small size. The groundmass is a clear brown glass, in which are numerous microlites of felspar, usually larger in size than those seen in (1201), also granules of enstatite. Iron ores are abundant, the crystals occurring principally in the glass, but also in the enstatite. The specific gravity of the rock is 2·653; the percentage of silica was kindly

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determined by Mr. J. Lewis, of the Government Analytical Laboratory, and found to be 60·8. The rock is, therefore, a typical enstatite-andesite.

On the east side of the volcanic neck there are many good exposures of the rocks along the road cuttings.

Here we find glassy andesites in great quantity, alternating with beds of crystalline doleritic lava, the layers of igneous material following one another with great regularity. On the south and south-east the beds have a northerly dip, and on the north and north-east a southerly inclination. In the middle the dips are very high, and in places vertical.

The area in which these bedded materials occur is on the border of the neck, and possibly we may have here a portion of the actual cone which was partly destroyed and then buried under later lava flows, but now partially revealed by denudation. At the north extremity of the neck there are again exposures of coarse agglomerate, penetrated by basaltic lava. It is probable that the andesitic lavas were a late product of the volcano. No similar beds were seen on the hills round about, but they may easily escape detection. It is probable that the Belmore volcano had a very long life, and that the latest lavas in the Barkly district were derived from it. None of the other large volcanoes show such a variety of igneous rocks.

14. The road from Belmore to the village of Rhodes is carried up a ridge of Cave sandstone, forming a gentle anticline, between the Bel River and the Bok Spruit.

On Glass Nevin, just before the highest point (6,800 feet) is attained, an outlier of volcanic rocks is met with, and the road passes over a small volcanic neck. A section of the neck has been laid bare on the western side, and we can see the tuff filling a vertical space in the Cave sandstone and in the sheet of hard massive coarse-grained lava overlying it.

The neck is filled with blue grey tuff containing many boulders of sandstone, doleritic lava, amygdaloid, etc.

15. On the farm Branksome, in the Sterk Spruit Valley, about five and a half miles south o Belmore, there is a small neck at the foot of the steep descent in the road towards the river. The length of the exposure is at least 200 feet, and the junction with the Cave sandstone is well defined, but its extent inwards, from the river, is uncertain.

The neck is filled with a very coarse agglomerate, consisting of blocks of dolerite, amygdaloid, and sandstone, usually altered to quartzite, the whole mass being of great hardness.

On the opposite bank of the river is a lenticular bed of coarse agglomerate resting upon Cave sandstone and overlain by doleritic lava. The latter bed occurs also around the neck, and is exposed in the road cuttings to the north. It is a massive medium-grained dolerite, which breaks up along joints into peculiar blade-like masses triangular in section.

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16. A little farther up the river, on the farm called Caerlave Rock, just above the junction of the small stream with the Sterk Spruit, is a similar neck penetrating the Cave sandstone.

The actual size of the pipe is not certain; it seems that the agglomerate of the pipe has also spread out over the surface of Cave sandstone for a certain distance around, and a vertical section through the neck would give a mushroom-shaped section of agglomerate.

17. Just behind the house is a small neck, not more than 100 feet aross, also filled with coarse agglomerate.

18. What must be regarded as the largest volcano in the Barkly East Division occurs in the Sterk Spruit valley, on the farms Broadford, Melrose, and Glengarry. Its actual limits are not clearly seen, except on the north and south, and it must have a breadth of about three-quarters of a mile.

On the north-east and south-west it is apparently overlapped by lava and ash, so that it stretches right across the valley a distance of more than a mile and a half. Its extent in these two directions is unknown.

As the Sterk Spruit has cut its valley right through the volcano, the latter is by no means conspicuous, a portion along the river being covered by alluvium, while on the hillside sthe outcrops are hidden by débris and grass.

On the north side the agglomerate, which is well exposed at a bend in the river close to the junction with the stream coming down from Ormidale, can be seen in contact with the Cave sandstone.

The junction runs up a very steep hillside, and there is fully 300 feet of coarse agglomerate exposed.

Both the agglomerate and Cave sandstone are capped with massive columnar doleritic lava, forming a lofty palisade, crowning the ridge, separating Melrose and Ormidale from Caerlave Rock.

Below the cliff (on Ormidale), apparently beyond the limits of the neck, there comes in the basal bed of ash, well seen, too, on Melrose and farther up the Sterk Spruit.

On the east, owing to this ash bed occurring down in the valley, it is impossible to trace the exact limits of the volcano.

In th ewest, on the farm Broadford, the lavas rest directly upon the Cave sandstone and the agglomerate; ash is rare, and then usually occurs higher up in the volcanic series.

Farther south and on Glengarry the basal ash bed comes in between the lavas and the agglomerate, and thickens rapidly. Near the farmhouse it covers a considerable area, extending up the small valleys and along the west side of the Sterk Spruit.

On Broadford and Glengarry there are fine exposures, showing jumbled masses of lava, both compact and amygdaloidal, pink, green, and purple ash, coarse agglomerate, and Cave sandstone, the latter often in masses of considerable size.

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The boundaries of the different groups are very complex, and can only be traced out completely on a very large scale map.

Fine cliff sections occur along the right bank of the river at the drift on Melrose. Some of the masses of Cave sandstone are so large that the possibility of their being included blocks is only revealed when the agglomerate is seen bursting through them and surrounding them on all sides. The sandstone is tilted, shattered, and baked at the junction to quartzite. Everywhere occur masses of pink and red tuff, like that overlying the Cave sandstone, penetrated by dolerite of different types.

The area resembles to a great degree that of the great volcanic centre of Telemachus Kop in the Stormbergen .

19. A number of miles further up the Sterk Spruit, not far from Johnston's Leap, on the bank of the small stream coming down from Kilcullen is a small exposure of coarse blue-green agglomerate. On three sides it is surrounded by Cave sandstone, and on the fourth there is a small alluvial flat. It is evidently part of a small neck, not more than about 20 yards in diameter.

20. East of Johnston's Leap, on the farm Narrow Water, are peculiar agglomerates, which indicate the presence of a volcanic neck.

About 250 yards up stream from the house there is an outcrop on the right bank of an agglomerate, built up almost solely of igneous material. Embedded in it are rounded masses of lava of varying size, much resembling bombs. They are light in colour and fine-grained outside, while their interior is darker, with large vesicles, containing zeolites.

All types of lava are present as inclusions, from dolerites to amygdaloids, but the predominant one is usually a black glassy type. The matrix is a black igneous material, in appearance very much like a tachylite, but very soft.

Under the microscope the bulk of the material appears to be a yellowish isotropic mineral, probably palagonite, produced by the alteration of fragments of basaltic glass. Small fragments of felspar are present.

Above this outcrop the ground rises rapidly, and we reach the bedded lavas overlying a thin bed of ash. The surface is strewn with fallen material, and it is impossible to see whether the agglomerate extends under the volcano beds. A little further up the stream, at a sharp bend, is a good outcrop of agglomerate, extending over a considerable area.

In the middle of the nearly vertical cliff of agglomerate is a thin lenticular bed of pale tuff passing into sandstone.

On the west side of the section the agglomerate is overlain by a thick bed of Cave sandstone, and this in turn by dolerite about 50 feet thick. The dolerite is not a lava flow, but a sill running westward towards Johnston's Leap. It lies nearly hori-

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zontally, is finely columnar, with numerous horizontal joints, making each column look like a stack of polygonal plates.

The bed of Cave sandstone is crowded with fragments of vesicular lava, usually rounded, and up to about eight inches in diameter.

It is evident that the agglomerate is a mass surrounding a volcanic neck. The volcano came into action early, and while the bed of Cave sandstone was in process of deposition, numerous bombs of lava ejected by the volcano fell into the layer of soft sediment currounding it. This volcano was probably situated a little southwards of this spot, but the intrusion of dolerite has apparently hidden it.

In the south of Narrow Water the bed of volcanic ash which usually rests directly upon the Cave sandstone is separated from it by a lenticular bed of doleritic lava for a distance of about a mile and a half along the outcrop.

This indicates a local lava flow prior to the deposition of the basal ash bed, and from what has been already said about the volcanic neck on Narrow Water, it is probable that the erupted material must have issued from it.

(iii) *The Volcanic Necks of Herschel.*

There are a number of volcanic necks in the division of Herschel, and no less than twenty-two were noted. Many of them approach in character the white tuff necks of Wodehouse, but there are several of them which are filled with yellow-white sandstone indistinguishable from Cave sandstone. So great is the resemblance that but for the fact that the material is seen forming a pyramidal mass in the Molteno or Red beds, it would be taken for an outlier of Cave sandstone.

When I commenced the examination of the Drakensberg, the evidence for such " volcanic sandstone " necks did not seem conclusive, and hence the sandstone mass on Kilchamaig (in Elliot, Tembuland) was doubtfully regarded as a possible vent.*

The study of the volcanoes in Wodehouse, and more especially in Herschel, removes all doubt and uncertainty regarding the nature of the sandstone mass of Kilchamaig.

The necks will now be described, commencing in the west of Herschel :—

1. The first of the necks forms a small peak, called Kiba Hill (or Kopje Alyn), a prominent landmark for many miles around.

It is situated close to the Orange River, about 5 miles north of the village of Herschel, and is a column about 120 feet in diameter and 150 feet high on a pedestal of Molteno beds (fig. 9). The tuff is very fine-grained, in some places a nearly

* Ann. Rept. Geol. Comm. for 1903, p. 189.

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pure sandstone, in others it is full of fragments of sedimentary material, white and grey sandstone and quartzite and dark shale. When fresh it is pale grey in colour, but weathers white and yellowish.

The contact with the surrounding strata, pebbly sandstones, is seen only on the east side of the peak. The slopes of the hill are covered with débris, while huge blocks of tuff, some over ten feet in diameter, are found near the base.

A thin horizontal sheet of dolerite, injected in mudstones, occurs just above the foot of this slope on the south-east side.

It is rather curious to note that between Kiba Hill and the Kraamberg (in Aliwal North), a distance of over forty miles, there is not a single volcanic neck to be seen.

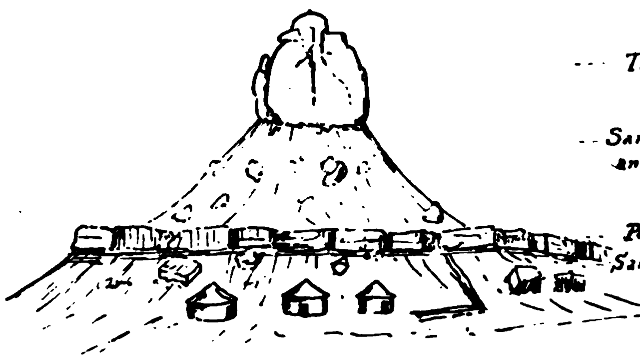

Fig. 9.—Kiba Hill from the south-east.

2. Between Kiba Hill and Herschel, and about three and a half miles from the village, is a peculiar mound of basalt, enclosed by a wall of white quartzite, and evidently a volcanic neck. The wall of quartzite is in places eight or nine feet above the surrounding surface, and forms a complete ring. At a distance of about six feet from the dolerite it passes into the typical gritty Molteno sandstone, and is therefore only a highly indurated form of the latter. Wherever dips can be made out, they are very high (or even vertical), and always inwards, while the rock is much slicken-sided, especially at the contact with the basalt. The latter rises with a gentle dome-shaped outline within the palisade of quartzite, the area occupied being about 120 yards long and 100 across. In thin section the basalt is seen to be a devitrified glassy rock of rather unusual character. Porphyritic crystals of plagioclase occur, both simple and twinned, the felspar being anorthite. Numerous inclusions of a greenish doubly refracting mineral are embedded in the felspar, often arranged in lines parallel to the planes of twinning. These patches are probably portions of glassy material containing incipient granules of augite.

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In the groundmass are minute needles of felspar, often projecting from the edges of the porphyritic crystals and in optical continuity. Otherwise they occur separate, and may often build up skeleton crystals. The groundmass is very dense, being composed of a nearly colourless glass, in which are crowded immense numbers of small rods, each one built up of a number of granules of augite. These rods form parallel or diverging bundles and often radiate out from the edges of the felspar crystals. Magnetite occurs in very minute crystals, disseminating throughout the groundmass.

A very few small crystals of olivine, now replaced by green serpentine, appear in the slide, but the very basic character of the rock is not very pronounced.

The density of the rock, 2·875, is very high for such a glassy type, especially as the amount of olivine and magnetite is so small. No tuff was anywhere visible within the vent, and the neck is entirely filled with this basalt. In the hand specimen the igneous rock exhibits a dull grey surface, covered where weathered by a brown skin. It thus differs greatly in character from the usual type of Karroo dolerite, the latter being usually coarse-grained and holocrystalline, and covered on weathering with a deep red friable crust. Such a dolerite forms a sill about 250 yards west of the pipe, and dipping towards it.

There are no volcanoes visible between this and the Gatberg, but midway on a direct line between Herschel and Bensonvale is a tiny outlier of Cave sandstone on a long spur of Red beds. The sandstone contains blocks of lava, several of which are of large size, indicating the proximity of a now-buried volcano.

A couple of miles north-east of Sterk Spruit is a flat-topped hill, crescent-shaped in plan, called the Gatberg; the main road to Palmietfontein lies on the north side of its base. The Gatberg itself represents a volcanic neck, and close to it are four smaller ones. A circle drawn with a diameter of one and a half miles would enclose the five vents. (Fig. 10.)

3. The Gatberg is a flat-topped hill, in plan somewhat like a crescent. At first sight it would be taken for an outlier of Cave sandstone with a thin covering of Volcanic beds; a closer examination disproves this.

The north and west face is formed of a cliff of unbedded siliceous tuff, weathering to a yellow or orange colour; the junction with the Red beds at its base being hidden by fallen material.

On the south-east and east the Red beds are exposed with a thin covering of Cave sandstone, the latter being well bedded with softer bands of shale and mudstone, and weathering to a pale whitish yellow.

At the north-east end the tuff cuts vertically through the Red beds. The junction with the Cave sandstone is not very sharp, but wherever it is distinct the surface of contact dips inwards at a high angle.

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It is probable that at the edge of the neck the friable Cave sandstone would tend to become crushed and broken, so that it has therefore acquired a great resemblance to the infilling tuff.

The tuff itself cannot in places be distinguished from the Cave sandstone, in other parts of the neck it is full of fragments of sandstone and whitish shale, well shown up on weathered surfaces.

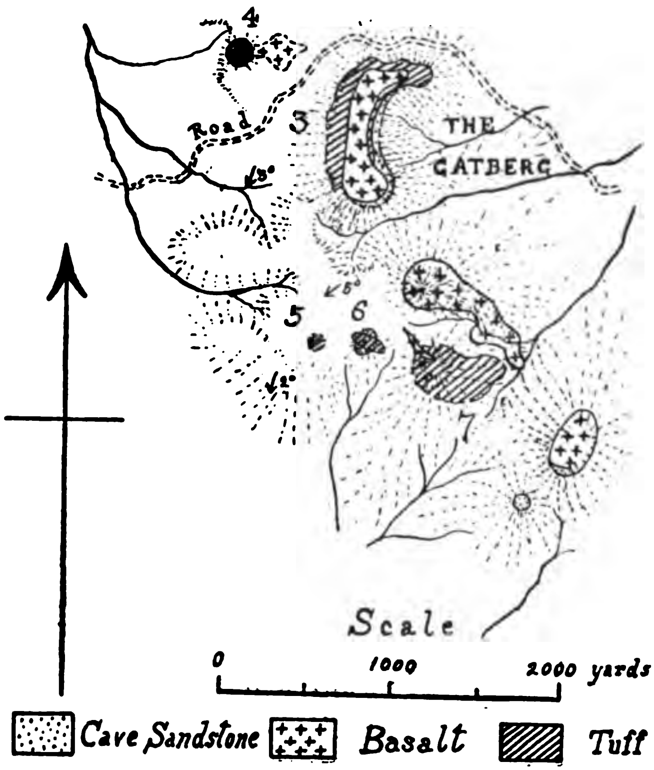

Fig. 10.—Map of the Gatberg group of Volcanoes.

Under the microscope it is seen to be built up almost entirely of small irregular quartz grains.

The basalt which crowns the hill is finely columnar at the base, but roughly jointed higher up.

In the extreme south it appears to rest upon Red beds, in the south-east upon Cave sandstone, and over the remainder of the summit upon tuff. It is very probable that this is an intrusive sheet of basalt, and not a lava flow. About a mile to the south-east are two hills touching one another at their bases, and formed of bright-coloured Red beds. One of these hills is capped with a cylindrical-shaped mass of Cave sandstone.

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The second has a small mass of Cave sandstone on one side, but the rest of the summit is composed of a horizontal sheet of columnar basalt resting upon Red beds.

Nearly a mile further to the south-east is an outlier of Cave sandstone and Volcanic beds, cut through by a slightly inclined sheet of columnar basalt. I think that these three detached masses of columnar basalt were at one time portions of a single intrusive sheet of igneous material. The microscope section (1218) shows it to be a basalt with a considerable amount of glassy base, pale brownish in colour, and crowned with long microlites of felspar, and granules of augite and iron ores. The intrusion belongs to the Stormberg Volcanic rocks, and not to the Karroo dolerites. The specific gravity is 2·888.

4. This is a very small neck on the north-west side of the Gatberg, the main road running between it and the latter. It is formed of a yellow siliceous tuff, usually closely resembling a sandstone, but in places crowded with fragments of shale and mudstone.

A thin sheet of basalt of small extent covers the ground on its east side, and may have been derived from this neck.

5. South of the Gatberg the Red beds have a steady dip of about five degrees away from that hill, and one of the fine-grained yellow sandstone beds forms a smooth dip-slope. About half a mile from the Gatberg on this sloping surface is a mound of angular masses of sandstone, rising as much as ten feet above the general surface. That this is not an outlying portion of a denuded bed of sandstone is at once certain, for not fifty yards away is a small rise showing red shales and mudstones capped with fine-grained yellow-white sandstone. The only conclusion that can be arrived at is that we have here a volcanic neck plugged with a sandstone-like tuff.

The tuff is brownish in colour, with a slight purplish tint; under the microscope it is seen to be composed almost wholly of sub-angular grains of quartz. There is hardly any cementing material, and the rock is very friable. The exposure occupies an area of about 50 yards in diameter; no contacts with the Red beds are visible.

6. About 200 yards east of No. 5 is a little conical hill, with red sandstone at its base and Cave sandstone on its flanks. It is gashed through from north-west to south-east, and the space filled in with volcanic agglomerate.

The walls are well-defined, and usually in contact with them is coarse agglomerate, with blocks of vesicular and compact lava sandstone, purple shale, and mudstone. In places the agglomerate has veins of igneous material ramifying through it, and the sedimentary fragments are extremely indurated. In the centre the lava is doleritic in character.

In thin section (1219) the rock appears much altered; the felspars are still clear and fresh, but contain numerous patches of

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calcite. The augite has been entirely replaced by green chlorite, with separation of iron ores. Large areas of calcite occur, perhaps replacing olivine, but probably in part derived from the alteration of the chlorite. The original rock was probably a sub-ophitic type of doleritic lava.

The pipe in which this occurs cannot be more than 200 feet long and 50 across.

7. Not much more than 100 yards from the last neck is another one, filled similarly with agglomerate.

On the north-east and east the agglomerate is siliceous in character, with large inclusions of sedimentary material (derived chiefly from the Red beds and Cave sandstone). Now and then patches of basic agglomerate occur with masses of doleritic lava intrusive in the same.

The neck extends down the hill slope on the south-east for a considerable distance, agglomerate, chiefly basic in character, forming this part of the vent.

The neck must have a length of close on four hundred yards.

On its north side there is a small dyke-like intrusion of dolerite cutting partly through the wall of the pipe (Red beds) and partly through the agglomerate, and forming a conical hill in the midst of the latter.

To the north is a conical hill of Red beds capped with a sheet of basalt, which descends the hillside on its south-eastern slope.

It may possibly represent a volcanic neck plugged with basalt, but I think that it most probably marks the source of the basalt which caps the Gatberg and the hills immediately to the south-east, as mentioned already.

8. About two miles south-east of the Gatberg is a small neck filled with yellow-weathering siliceous tuff.

On the spur above the main road from Sterk Spruit to Majuba Nek, close to the Krom Spruit, are three volcanic necks, each surrounded by Red beds.

9. The largest one is perched up about 500 feet above the road, and forms a lofty conspicuous pinnacle.

The neck is rather elongated in a north and south direction, and is filled with a siliceous tuff, which can hardly be distinguished from Cave sandstone, except for the absence of bedding and (in places) a slightly darker colour.

On the west side the tuff contains occasional pebbles and fragments of sandstone and light coloured shale.

10. A little higher up is another and smaller neck, also filled with siliceous tuff.

11. The third neck is much lower down, not far from the road. It is small, probably not more than 20 yards in diameter, but the tuff is much coarser in character than in 9 and 10, and blocks of lava are not uncommon. A peculiar variety of tuff is vesicular, the cavities being filled with soft brown earthy material. In places it is slightly calcareous.

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12. From the Krom Spruit the road to Majuba Nek rises rapidly, and finally reaches a spur called Roode Nek, about 700 feet above the spruit. The purple and red mudstones of the Red beds are well exposed, and hence the name given to the ridge.

The road makes a complete bend round a small kop, which, on examination, is found to be a volcanic neck.

In size it is about 200 feet by 75 feet, but shales and mudstones adhere to the core of agglomerate, and make it seem smaller. The agglomerate is in places very siliceous, with small fragments of sandstone; it is pale bluish in colour, and weathers like a mudstone. There are, however, enclosures of lava and dolerite of considerable size.

Occasionally some of these masses of vesicular lava are spherical, compact on their exteriors and vesicular within, evidently being of the nature of bombs ejected by the volcano, and which have fallen back within the vent.

A thin dolerite sheet from three to four feet thick, an offshoot from the great dyke crossing Majuba Nek, cuts through the neck along its major axis (nearly north and south). At the south end of the neck the strata are affected by a small north-west and south-east fault.

13. In the valley of the Blikana River not far from its junction with the Telle is a prominent stack of yellow siliceous tuff projecting from a spur of Red beds.

14. A small neck occurs in the valley of the stream, called by the Basutos the "Famine" River. The neck is very small, and is filled with dark agglomerate, with numerous blocks of igneous material.

15. Further down the "Famine River," about half a mile before its junction with the Telle, is a volcanic neck plugged with basalt. The river has cut round one side of it, and the contact with the yellow sandstone forming the wall is very distinct. The beds on the south-west and west are much disturbed, and dip away from the basalt, with an angle as high as 20 degrees.

The basalt is very fine-grained near the walls of the volcano, and is coarser towards the centre.

In thin section (1221) a few porphyritic crystals of labradorite felspar are present, embedded in a glassy groundmass crowded with extremely minute prisms and granules of augite, together with a smaller number of small stumpy felspar laths. Olivine is represented by a few pseudomorphs in serpentine and calcite. Magnetite is not very abundant. The specific gravity of the rock is 2·833.

North of Dulcie's Nek is a long ridge, on which are situated four volcanic necks.

16. The first of these is rather large, and is filled with dark greenish agglomerate, with numerous inclusions of lava.

The strata on south, east, and north dip inwards at high angles,

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and the Cave sandstone on the south diminishes rapidly in thickness towards the vent until at the contact it becomes quite an insignificant bed. On the west the bedded lavas dip inwards towards the neck, and the boundary is not very distinct.

17. The second neck lies a little over 500 yards farther north, and consists of a cylindrical plug of white tuff cutting through Red beds, lavas, and Cave sandstone. The latter is very thin on its southern border, while to the north it is completely absent for several hundred yards.

18 and 19. Further north still, on the ridge marked M'Dofela on the divisional map, are two small tuff necks, surrounded by Red beds.

There seems to have been considerable disturbances during the existence of these four volcanoes. The Cave sandstone is thin, and in places entirely missing; midway between Nos. 17 and 18 the lavas rest directly upon Red beds for a distance of about half a mile. A couple of miles due west of No. 18 the Cave sandstone is again absent.

Due north of No. 19 there are two beds of sandstone, separated by a thick bed of lava, the lower stratum being thinner than the upper one.

20. No. 20 is a neck filled with basic agglomerate at the top of a ridge midway between Dulcie's Nek and Governor's Drift.

It cuts through Cave sandstone and Volcanic beds, and the strata dip inwards at an angle of about 20 degrees.

21. A mile and a half north-east of Governor's Drift is a very prominent neck of white weathering siliceous tuff on a rounded height of Red beds overlooking the Orange River.

Towards the north-east, in the Orange River Colony, is another prominent tuff neck. Its western face is very precipitous, and it is locally known as Hanglip.

22. The last volcanic neck noted in Herschel occurs on a flattish hill of Red beds in the extreme north of the district opposite the point where the Maputsang River comes down from Basutoland and unites with the Orange River. It is similar in character to No. 21.

In Basutoland, close to the schoolhouse at the Masitisi Mission Station, is a small volcanic neck filled with dark greenish agglomerate, rather coarse in character. It is not more than 20 feet across, being the smallest neck of all those mentioned in this report.

Sandstone and Agglomerate Dykes.

A few occurrences of sandstone in the form of dykes have already received a certain amount of attention, but there are several which yet have to be described.

On Wolve Kloof (in Wodehouse), between the homestead and the "poort," the road crosses a sandstone dyke which trends

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north-west and south-east, and which can be traced for about 200 yards. It has a maximum width of four feet, and in places forms a ridge several feet above the general surface of the ground. The material forming the dyke is a fine-grained, friable, whitish sandstone, crowded in places with small fragments of whitish or bluish shale. Under the microscope it shows identical characters with the normal type of Cave sandstone. Probably it is a fissure formed during the formation of the latter, perhaps by an earthquake, the crack being afterwards filled in from above. A similar dyke occurs cutting through Red beds in Herschel, about three miles due south of Palmietfontein. The course of the dyke up the hillside is very irregular, and it only extends for a short distance, the maximum breadth being about three feet.

The most important of these dykes was noticed close to Palmietfontein. It has a length of about four and a half miles, and is perfectly straight.

It commences in the angle between the "Famine" and the Telle Rivers, and forms a great ridge, flanked on either side by Red beds. At this extremity it appears to swell out, but farther along it is a regular dyke, with a width of from ten to fifteen feet, accompanied for a short distance by a narrow parallel dyke about thirty inches wide and of similar character.

It crosses the gorge of the "Famine" River, and cuts through the steep-sided tableland on the left bank of the latter, thus exhibiting a section 900 feet in height from the river bed upwards.

It cuts through both Red beds and Cave sandstone, and to the south-west gives rise to a fine wall over twenty feet in height. It crosses the river a second time, thinning out and terminating at the base of a tableland crowned with sandstone. The dyke is composed of a fine-grained yellow sandstone, indistinguishable from Cave sandstone, but at a number of points along its course it contains abundant fragments of sandstone, quartzite, and shale, and, at one point at least, numerous boulders of amygdaloid and dolerite. In this respect the infilling material resembles to a great degree that filling many of the volcanic necks in this district and in Wodehouse.

The purple mudstones and shales have not been appreciably indurated on either side of the dyke, and it is difficult to believe that it was formerly a fissure of eruption.

It is unfortunate that the lavas have been denuded off the tableland at this point, so that it is impossible to see how far into the lavas this dyke passed. It may be a long earthquake fissure filled in with sandstone during the deposition of sedimentary material, thin beds of which occur close at hand in the midst of the lavas.

The dyke is almost vertical. At the entrance to the deep gorge of the "Famine River" both it and the Cave sandstone are

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faulted down towards the north-east, the line of fault being occupied by a thick dolerite dyke striking north-west.

The sandstone dyke has been shifted laterally by the fault a distance equal to its own breadth.

At Karnmelk Spruit (in Aliwal North), just behind the hotel, is a peculiar dyke-like mass of volcanic agglomerate, probably marking a fissure of eruption. The dyke extends eastwards across a loop of the Karnmelk Spruit near the bridge, and has a length of about half a mile. Contacts are not well seen, but the dyke is usually about eight feet wide, with a nearly vertical dip; behind the hotel it swells out to a width of at least 30 feet, apparently terminating in a knob. Along the greater part of its course the material forming the dyke is composed of hard greenish agglomerate, in which igneous fragments are abundant.

The large extremity is crowded with blocks of sandstone, shale, and fine compact white rock set in a dark greenish groundmass of decomposed tuff-like material. The white rock would be taken in the field for a fine tuff, but in section (1213) under the microscope it appears to be a devitrified glassy lava with phenocrysts of felspar and elongated patches of calcite filling-in vesicles. There are fragments of grit in the rock, and probably by the increase of foreign material the rock passes over into a tuff. A great mass of material in the neck is very vesicular, and is probably an altered lava penetrating the agglomerate. There are peculiar dark blue-black lumps in the agglomerate, containing abundant disseminated sulphide of iron, probably marcasite. These nodules are usually surrounded by an ochreous shell, due to weathering. Marcasite or pyrites occurs in the igneous material also, in large quantity, distributed rather irregularly. Near the bridge the agglomerate is cut across transversely by a small dolerite dyke from eighteen inches to two feet in width.

VIII. Volcanic Activity in this Area.

The large number of volcanic necks enables certain views to be formulated with regard to their distribution, mode of origin, and history. First of all it must be noted that they are distributed most irregularly, sometimes crowded closely together, at other times separated by considerable intervals. A large number of necks which are probably present must still remain buried beneath the lavas of Barkly East and Herschel, consequently any conclusions from those exposed, with regard to their distribution, must necessarily be uncertain.

So far as can be judged, there seems to be no evidence whatever of the vents being arranged along definite lines, and in this respect their distribution is similar to that of the volcanic necks of Central and East Scotland, the Auvergne, the Eifel, and Swabia. At no point has the position of any one of these orifices been determined by pre-existent lines of faulting in the Storm-

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berg beds, which is quite in agreement with the trend of modern opinion.

This independence is also indicated by the fact that in the Elliot division the perforations must pass through a thickness of over 4,000 feet of Stormberg beds alone, against a thickness of from 2,000 to 2,500 feet only in Wodehouse and Aliwal North.

The earliest of the volcanoes were probably those in the vicinity of the Waschbank Peak. Many had a brief existence, and were soon buried by the ejections from their more active neighbours. The history of some of the larger necks can in many instances be fairly well made out, but the majority of the smaller necks, and especially those filled with siliceous tuff, have left but very imperfect records of their activity.

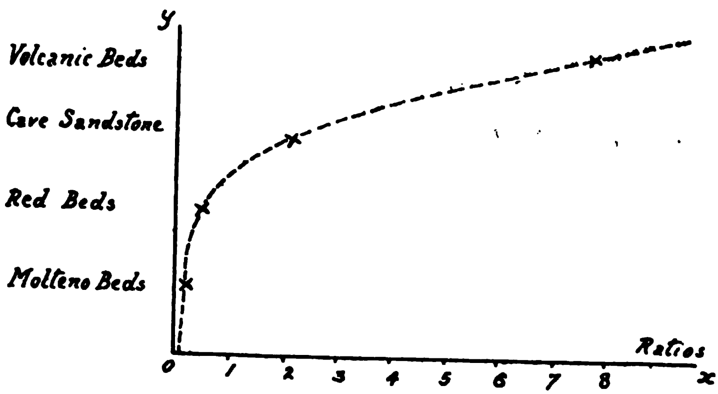

Fig. 11.

If the volcanic necks are classified according to the kind of material which is predominant in them, we have four main types which shade off one into the other. These types are:—

(*a*) those filled almost entirely with basaltic or doleritic lava;

(*b*) those in which an agglomerate is present with numerous blocks and fragments of amygdaloid and dolerite;

(*c*) those filled with siliceous tuff or agglomerate in which masses of sedimentary rocks predominate;

(*d*) those filled almost entirely with fine-grained sandstone.

It is usually believed that different types like these indicate different manifestations of volcanic activity or show that the pipes have been filled up in different ways, but there is much probability that types (*b*), (*c*), and (*d*) are, in some cases, merely phases which may occur at different horizons in the pipes. That is to say, if we could follow a pipe downward from the top into the interior of the earth, its contents would, within a certain limit, become more and more *siliceous*.

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In figure 11 these types have been arranged into two main groups, namely, (A) those with preponderant basic igneous inclusions, (types *a* and *b*), and those (B) composed entirely of siliceous material (types *c* and *d*). The necks are collected together according to the position of their exposed denuded tops in the Stormberg sequence. The *ordinates* represent geological horizons, from the Molteno beds upwards, the *abscissae* give the corresponding ratio of the number of volcanoes on that horizon grouped under (A) to the number grouped under (B); or, roughly speaking, the ratio of the number of basic to acid necks.

The curve which has been plotted in this way is derived from the analysis of the contents of over eighty necks, and shows that the material filling the pipes tends to become more and more *basic* when followed in an *upward* direction.

Where a neck is filled entirely with tuff and agglomerate, without any intrusive masses of igneous material, two views may be put forward in explanation, either

(i) the fragmental material has been produced by the very first outbursts which led to the formation of the pipe, no lava having followed; or,

(iii) the lava following has been completely ejected and the pipe filled with fragmental material.

In the intermediate stage (ii), where the agglomerate is penetrated by a mass of lava, we can get all gradations from a pipe in which the intrusion is of insignificant proportions to one in which lava entirely fills the vent. Sometimes a very small patch of agglomerate still remains on one side of the igneous plug. It is possible that many volcanoes, provided they have a long life, pass through such a cycle of changes as thus indicated; from stage (i) through (ii) to (iii), then to (ii) again, and so on. That these alternations of character of the material in the vent should be recorded by a corresponding variation in the nature of the ejected products is, I think, not necessarily true.

For example, in Matatiele, Mr. Schwarz has noticed a large number of volcanoes which have reached stage (ii), or a later repetition of the same phase, and yet the Volcanic beds contain practically no masses or layers of ash and tuff, which it would be only natural to find as marking the explosive outbursts from the vents.

The same is the case in Wodehouse, and in Herschel, where volcanic rock is almost the only material which has been spread out around the volcanic throats.

With regard to the nature of the agglomerate in the pipes during the period of activity, we can only surmise that it was friable and unconsolidated, and, if the volcano was subaqueous, permeated with water, so that it would tend to behave like a plastic material.

Let us now imagine a mass of molten material rising up in the pipe, impelled from below under the expansive force of

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highly heated water-vapour. Te lava would make its way through the soft agglomerate, and would flow out at the orifice until the pressure below was relieved. It it were followed by much steam and vapour, a portion of the fragmental material might be ejected after the lava, and go to form a bed of tuff. Otherwise the lava might simply make its way quietly through the agglomerate, without much disturbing the latter. A small amount of induration would be produced; but in all the vents hitherto examined this alteration extends to a distance of only a few inches from the contact with the igneous rock.

In fact, the lava might rise up through the soft agglomerate, as a bubble of oil rises in a tube filled with water.

There is apparently a certain amount of adhesion between the agglomerate and the walls of the pipe, and the settling down of the contents after each eruption is perhaps sufficient to explain the inward dip of the strata around the vent, indicating a downward drag. Returning now to a consideration of the different types of tuff and agglomerate necks, we find that the type (i) is perhaps less frequent than we are at first led to conclude. There certainly must have been some necks filled with materials formed by the first outburst, an explosion which was not followed by any lava. These necks would be soon buried beneath the lavas from more active centres. Now, in Wodehouse almost all the necks belong to the group (B), and have hardly any igneous fragments as inclusions. Obviously, if no lavas had issued from these vents, it would be impossible to account for the Volcanic rocks which must have extended across from Barkly to Molteno in a mass of immense thickness.

All through the Drakensberg these tuff necks are abundant, and we are forced to conclude that they represent pipes from which lavas must at one time or other have issued. The question then arises as to the source of this tuff and agglomerate, and we see that the material may have come either from below, above, or from the sides.

In the first case the lava would be entirely ejected from the orifice by the heated gases, and a large quantity of material carried up after it. This material is partly composed of portions of the surrounding rock and masses brought up from below, it being remembered that any mass of pulverised material always occupies a greater bulk than the original solid rock. It is probable that most of the stuff which has been derived from below has not been raised through a very great height. The great bulk of the inclusions in the agglomerates consists of masses of shale and sandstone, recognisable as having come from the Stormberg beds, but there are a fair number of boulders of white and bluish-white quartzite like that of the Witteberg and Table Mountain series, and sometimes fragments of rocks which are certainly derived from the Pre-Cape formations. I have never yet noticed any fragments of granite or gneiss. Yet

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microline, orthoclase, epidote, and zircon are common in all the tuffs and agglomerates. This shows that these minerals are derived from the sandstones of the Stormberg series, particularly from the Cave sandstone, and not from granite deep down at the roots of the volcano.

Sir A. Geikie has noticed that in the volcanic necks of East Fife, which penetrate Carboniferous strata, no fragments of any sub-Carboniferous sedimentary rocks have yet been recognised. In many of the necks in this area it is quite evident that the agglomerate, round the walls, has been formed almost *in situ*; for example, in the Belmore volcano the material in contact with the rim of Cave sandstone is formed of this same sandstone, much pulverised, but with occasional angular blocks of the latter. Towards the centre of the pipe there are abundant masses of red shale, quartzite, lava, etc.

As this mass of siliceous agglomerate follows immediately after the expulsion of the lava, we naturally expect to find that blocks of the latter would occur in the pipe, towards its upper limit.

The higher we go, the greater would be the number of igneous inclusions, until the agglomerate may come to be composed almost wholly of masses of lava set in a matrix of igneous ashy material.

The results obtained from the study of figure 11 justify this view, for those agglomerate necks which occur surrounded by bedded lavas are filled with a material principally igneous in character.

In the second case, where the infilling has been from above, we can include the greater number, probably nearly all, of those necks which have been included in type (*d*), *e.g.*, those filled in almost entirely with fine-grained sandstone.

It is well known that during an eruption a volcano may completely clear out its pipe, and if its activity ceases for a time, a huge empty pit is left in the strata. Now the volcanoes in this area were certainly sub-aqueous in character, and, as we have already seen, sediment was continually being deposited during periods of quiescence, thus forming beds of sandstone between the lava flows.

The immediate result would be the infilling of the pipe with arenaceous material, carrying with it a certain amount of ash, boulders, and bombs of lava from around the orifice. Thus the pipe would become plugged with sandstone, containing igneous inclusions and occasionally fragments broken off from its walls. The greater number of the necks in Wodehouse, and some also in Herschel, are of this character, and the sandstone filling them is indistinguishable from Cave sandstone. The quartz grains are often rounded, and there are the same conspicuous accessory minerals as in the latter. Perhaps the best example of such a neck is No. 13 in Elliot, mentioned in last year's report. In the

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midst of the sandstone filling the pipe is a thin bed of quartzite, exposed at several places, and always having a dip, though variable, inwards towards the centre of the neck. This quartzite is formed of grains of clear glassy quartz, rounded to angular, cemented by chalcedonic silica. In it are pieces of silicified wood like that occurring in the Cave sandstone.

The peculiar sandstone dykes at Wolve Kloof, Donnybrook, and Palmietfontein have already been described, and support the view that the material filling a pipe of this nature is not a pyroclastic rock, but is composed in great part of arenaceous sediment. In a pipe filled in from above we may expect igneous inclusions to be more abundant as we proceed higher up, this being in agreement with the results obtained from figure 11. It is noteworthy that masses of lava occur in the Belmore volcano containing bands of pipe-amygdales. There can be no doubt that these are portions of bedded lavas which have tumbled down into the neck.

The large volcanoes of this area have evidently been filled in, partly from above, and partly from below; indeed, it is hardly to be expected that the material in any one pipe should have been derived from one source alone. Blocks must have been continually brought up from below by the explosions, while masses from the ides must have tumbled down the pipe, and fine sediment been deposited in it from suspension. In this area the whole of the lavas have evidently issued from volcanic necks; there are no indications of any fissure-eruptions. Indeed, the walls of the volcanic necks are usually cleanly cut through the sedimentary rocks, and the latter are never faulted, fissured, or traversed by dykes radiating outwards from the pipe. From the detailed description of the Volcanic beds it will be gathered that the earlier phases of activity were characterised by ejections of ash alternating with lava, the later phases by lava-flows only.

The eruptions in this area were heralded by earthquakes, and the strata at Siberia and Xalanga Peak were faulted prior to the outflow of volcanic rock. Local erosion of the upper portion of the Cave sandstone is not very infrequent, and points either to strong currents or else to disturbances in the immediate neighbourhood of volcanic centres, caused by explosive outbursts. In fact, it is very surprising that the strata are so regular in character up to the very edges of the necks even. These earthquakes may also have produced fissures in the strata, which were then filled in with sandstone, *e.g.*, Wolve Kloof. The disturbances were succeeded by lava flows of limited extent, most of which occur in the midst of the Cave sandstone.

After these earliest flows the greater number of volcanoes came into existence, and there was a general gradual subsidence over the whole area. This depression of the earth's crust, which continued to about the close of the period of volcanic activity, may be due, either to gentle folding in the strata, or to the re-

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moval from beneath the crust of such a large volume of erupted material.

In the central portion of Barkly East, around Belmore and Moshesh's Ford, and again along what is now the Kraai River valley, two local areas of subsidence were formed, but the shallow basins were rapidly filled with bedded rocks. Lava flows were frequent, and each was followed by a period of quiescence, during which beds of sandstone were deposited. Each fresh outburst caused the ejection of fragmental material and volcanic bombs, which fell into and became embedded in the sediment surrounding the necks.

Eruptions then became general throughout the area, and were principally of the explosive type.

The great bed of ash in Barkly and on the Elliot border was laid down, the uniform nature of the material indicating that it was formed continuously, and without a pause.

Occasionally a rapid thickening of the ash bed has been noticed, which probably indicates the proximity of a neck; but if an ash-cone were formed below water it would not be long before the material was disintegrated and spread nearly uniformly over the floor of the lake.

In the case of the lavas a thickening is more difficult of detection, but in a few places a high inclination in the beds, in comparison with flows immediately above or below, probably shows that the material was formed close around the orifice of the pipe.

In the west of Barkly and in Herschel no explosive eruptions occurred, and in consequence the volcanic products are entirely lavas.

Around Belmore, on the other hand, there were continual outbursts, as indicated by the alternations of tuff and lava. It is probable that the large volcano here was one of the dominant centres during this period. After these explosive eruptions a great outpouring of lavas took place, by which the smaller and less active volcanoes were overwhelmed and buried. Small inequalities on the floor of the lake were hidden and the areas of subsidence filled, giving a smooth and regular surface of volcanic rocks covered by water.

This is indicated both by the layers of ash and sandstone and by the horizons of pipe-amygdaloid around the town of Barkly East. Thus while the lavas and ash beds have a general dip to the north, the inclination of the pipe-amygdales on a great number of different horizons and over a large area, indicates that the lava very commonly flowed from north to south. The same kind of evidence is obtainable on the north side of the syncline and also in the east of the district, consequently we must come to the conclusion that these higher lava flows spread out over a nearly horizontal surface, even across those depressions formed by subsidence.

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This shows, too, that the great syncline of the Kraai River valley is later than the lavas. It must be noticed, too, that its axis does not cross the centres of the areas of subsidence produced at the commencement of the eruptions. Hence, after the preliminary movements of the earth's crust, the whole tract must have subsided uniformly. That this area must have been covered by water is indicated by the frequent intercalations of sandstone and ash, and also by the horizons of pipe-amygdaloid.

It is probable that the later eruptions were sub-aerial in character, due either to the filling up of the basin, the displacement of the water, or elevatio nof the whole area. As the lavas increased in thickness more and more of the volcanoes were put out of action, while eruptions were confined to the more dominant centres.

The thickness of erupted material is in this area never more than about 3,000 feet; but at Ongeluk's Nek, in Matatiele, Mr. Schwarz found the lavas to exceed 4,000 feet, while in Natal, according to Mr. Churchill,* they are thicker still. It is evident that a vast amount of rock has been denuded away, so that probably the capping of Volcanic beds exceeded 4,000 feet over the whole of this area. There is no apparent thinning towards the south, at the edge of the Drakensberg, for in several places there are precipitous cliffs of lavas about 2,000 feet in height, and judging by the evenness of the various flows, the lavas may have extended for many miles further south and south-east.

It must be noted that no volcanic necks have yet been found in the south of Elliot or in Xalanga, so that the southern limit of the belt of volcanoes is quite close in under the Drakensberg escarpment.

It is evident that the lavas which formerly extended southwards, consisted of material erupted in the north, but which flowed southwards. Taking a maximum thickness of 2,000 feet at the edge of the present escarpment, and assuming that the minimum inclination sufficient to cause flowing is one degree, we find that the lavas would have extended a distance of over twenty miles south of their present limit.

The geological age of the volcanoes and the volcanic rocks is probably Lower Jurassic.

The Molteno beds, from the evidence of the plant remains, may be considered of Rhaetic age, and the Red beds (or at least the upper portion of them) and the Cave sandstone may be Liassic, a view corroborated by the presence in them of crocodiles with distinctly Liassic affinities.

The lava flows would then have commenced in the Lias, and may range possibly into the middle of the Jurassic period, but it is impossible to obtain any idea of the length of time occupied during their formation. It is interesting to find that in India the

* F. Churchill. Trans. S. A. Phil. Soc., Vol. x., pt. 3, 1898.

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Rajmahal group, consists of a great thickness of compact and vesicular basalts, with very thin interbedded sandstones and shales, containing plant remains. The age of these beds has been shown to be slightly older than the Inferior-Oolite of England,† and thus the period of volcanic activity in India must have corresponded almost exactly with that in the Drakensberg area.

IX. The Dolerite Intrusions.

The dolerite sheets and dykes which are met with in this area form part of the great network of igneous intrusions which penetrate the beds of the Karroo formation throughout the Colony, and which in consequence have been termed Karroo Dolerites.

The intrusions are the product of a later phase of volcanic activity than that which gave rise to the Volcanic beds of the Stormberg series, for dykes of dolerite are often found penetrating many hundreds of feet of bedded lavas.

The Karroo dolerites are very similar in character to most of the compact lavas of the Drakensberg, but I think that in almost all cases the two groups of rocks can be separated by petrological examination. In very many cases the dykes or sheets when followed are found to unite with the general network of Karroo dolerite intrusions, and never to be cut by them.

The dolerites vary greatly in character, according to the conditions under which they consolidated, but one important feature about them all is their specific gravity, which is always higher than that of any of the holocrystalline lavas in this area. The specific gravity varies between 2·93 and 3·01, which is practically identical with specimens from the western part of the Karroo. In one case the density is as low as 2·86 (specimen from Sterk Spruit, Herschel), but the rock in this case is of an unusual type, and there have been mineral changes as well.

The lavas, on the other hand, have a density of from 2·82 to 2·91, the maximum in this area, but some of the glassy and more acid rocks range considerably lower.

The dolerites vary from fine-grained rocks, sometimes with a small amount of glassy base, to extremely coarse-grained ophitic examples, in which the crystals of augite may attain a diameter of nearly one-third of an inch.

These coarse-grained dolerites are very prominent south of the Drakensberg, around Indwe, Cala, and Engcobo, and are also met with occasionally in Aliwal North. The common type of dolerite, usually forming narrow dykes or thin sheets, is a medium-grained rock, in which ophitic structure is common, but examples in which the augite occurs in the form of granules is just as frequent, and between these two extremes we have a

† Seward. Q.J.G.S. Vol. 59, p. 227, 1903.

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structure which may be termed sub-ophitic. Occasionally we find dolerites in which porphyritic structures exist, and a few of these and other exceptional types will be described later on.

For convenience in considering the distribution and characters of the dolerites it will be well to divide them, according to the mode of occurrence, into sheets and dykes.

Sheets are very abundant in Elliot and Xalanga, and often become laccolitic in habit. They either cut nearly horizontally through the strata or have a slight dip to the north and north-west.

At Dordrecht there is a thick sheet which crowns the ridge immediately to the east of the town, and which dips east-south-east. It is finely columnar to the north-east, and forms a gigantic palisade. The sheet was not followed westwards beyond the railway station, but towards the north-east it was traced for many miles, and was found to cross the Waschbank River just south of Wolve Kloof.

The river has cut a narrow gorge through the sheet, which here dips steeply to the south, and from the road cutting good specimens of the dolerite can be obtained.

The normal rock is a compact coarse-grained ophitic dolerite, but at the south end of the road cutting it is drusy, and has occasional cavities, as much as two inches in diameter, lined with crystals of felspar and dark augite. The rock from the north end of the cutting is very coarse-grained and spotted in the hand specimen; on weathered surfaces large patches of dark green augite project; they are sometimes as much as three-quarters of an inch across.

In thin section (1224) the rock appears to be composed of lath-shaped plagioclases, aggregated together in some parts of the section, and enclosed ophitically by large plates of colourless augite in other parts, this giving the rock the spotted appearance noticed in the hand specimen. Olivine occurs as small granules embedded in the augite, and mostly altered to deep green serpentine. A few large irregular patches of magnetite occur, apparently moulded on the felspars. The specific gravity is 2·987.

In a section (1225) from the central portion of the dyke the dolerite shows different characters. The plagioclase and augite have grown independently, and are in part idiomorphic and in part mutually interfere. The spaces between the crystals are often large, and are occupied either by a more acid plagioclase or more commonly by a delicate micrographic intergrowth of quartz and felspar crowded with minute needles of apatite and granules of iron ores. The colourless augite has in great part been altered to a brownish fibrous-looking diallage, this alteration usually affecting the crystals along their edges, but often most irregularly. The specific gravity of the rock is only 2·907.

The central part of the dyke has apparently suffered the most alteration. In section (1226) the structure is almost the same

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as in (1225), though the augite originally formed longer crystals. The mineral has been completely changed, first to diallage and afterwards to bright yellow, strongly polarising serpentine, in which the platy structure of the diallage can still be made out. Long needles of apatite are abundant.

The dyke encloses portions of the sedimentary material through which it cuts, and in places has altered them to a great extent.

One of these contact rocks, originally a mudstone, is pale buff in colour, with white spherules. In section (1227) the rock seems to show complete crystallisation, and the outlines of the small original quartz grains are no longer visible. The rock is composed largely of minute prisms of clear felspar, untwinned, and probably orthoclase, crowded together or grouped in radial aggregates and set in a groundmass of colourless to brown micaceous and chloritic material. Epidote occurs in small colourless granules, and there are aggregates of nearly opaque hydrated iron ores.

Some miles to the north-west of Wolve Kloof on Hartebeeste Valley, is a great intrusion of dolerite, lenticular in form, with a small dip to the south-east.

On Toom Nek, Teken Fontein, and Hartebeeste Hoek nearly horizontal sheets of dolerite occur, a rather unusual feature in the Wodehouse division, where most of the sheets are inclined. Farther to the north-west the Holle Spruit passes through a narrow and deep gorge, cut through a thick dolerite sheet, which, though horizontal at first, rises gradually towards the north-west, and which gives rise to a ramification of sheets and dykes in the valley of the Telemachus Spruit.

On the farm Klip Fontein there is a ridge formed by an immense mass of coarse-grained dolerite about a mile and a half in length and a mile in width. It is of considerable thickness, and is apparently laccolitic in habit, having no marked connection with any of the other great intrusions in the neighbourhood.

Between the Kraamberg and the Stormbergen is another large area occupied by coarse-grained dolerite, whose mode of occurrence is typical of those intrusions which occur almost isolated from one another. A section drawn through this area would show the dolerite to have an outline when projected on a vertical plane of a gigantic hand with fingers outspread. The arm and wrist would represent the main mass, usually concealed below ground, while the fingers represent sheets which arise from the main mass, and are parted by sedimentary material.

On Ruigte Fontein is another dolerite intrusion with similar features. East and south-east of the town of Aliwal there are only a few small sheets of dolerite, most of the intrusions being in the form of narrow dykes. The large sill which crosses the Kraai River near Oorlog's Fontein is a very coarse ophitic dolerite.

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In section (1229) the augite forms very large plates, which are crowded with felspar laths, while a few granules of olivine are also enclosed. A few minute patches of biotite occur in the angles between the felspars moulded upon the iron ores. A small amount of quartz is contained in the groundmass. The specific gravity of the rock is 3·000.

In Herschel the dolerites in the western portion of the district show evidence of having been injected into the strata with considerable force. Almost every sheet and dyke sends out tongues into the beds, or is accompanied by thin irregular dykes and sheets, so that very often it is impossible to map the boundaries of the dolerite, except in a generalised way. About a mile north of Herschel, where one of these intrusions crosses the river, a part of the dolerite is light greyish in colour, containing prisms of a mineral whose faces have a silvery lustre, so that the rock appears to be very rich in ilmenite. In section (1217), however, these prisms are proved to be crystals of a nearly colourless augite, which have been altered in part to diallage, and which sometimes attain a length of a quarter of an inch. In the slide all transitions from fresh augite into the finely striated diallage and that again into pale serpentine are beautifully clear, and the alterations have affected the crystals very capriciously. The felspars have given rise to a large amount of brownish doubly-refracting granular material with flakes and patches of chlorite, and are milky white by reflected light.

Between the Bamboes Spruit and the Sterk Spruit the strata are injected with numerous sheets of coarse-grained dolerite, which traverse the beds in a highly irregular manner, though with a general dip to the north-east. A section (1220) taken from a sheet on the right bank of the Sterk Spruit, close to the drift, shows very peculiar features.

The augite, which in places is partly altered to diallage, occurs sometimes in long prisms, but is more commonly intergrown with the felspar. Parallel, radial, and even micrographic intergrowths are present; the commonest is the second type, which gives a stellate appearance.

The later felspars are more acid in character than the earlier, and occur in shapeless patches, sometimes graphically intergrown with quartz. There is some serpentine, which probably represents altered diallage. Iron ores occur in very small crystals disseminated through the rock. The specific gravity is only 2·861.

There are large intrusions in the valleys of the Blikana and Telle Rivers, the direction of the dip of the different sheets being extremely variable.

In Barkly East there are hardly any intrusive sheets, the only one calling for notice being an annular dyke, of which portions are exposed at the heads of the valleys of the Long Kloof River and the Sterk Spruit.

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This intrusion penetrates the Cave sandstone, but never the lavas or ash-bed and its extension beneath the Volcanic beds is indicated by dotted lines in the map.

It appears in the south-east, near Burgher's Nek, and strikes north-east past Fetcani Pass, and disappears below the lavas at Belleville. On Rosehill it reappears for a short distance, crossing the valley almost at right angles.

In the valley of the Sterk Spruit this sheet is very prominent, striking due east as far as Narrow Water. The curve is not completed in Barkly East, but possibly its eastern part may be exposed in Maclear. The dip along the curve is always inwards, at an angle of from ten to thirty degrees.

The dolerite is always very coarse-grained, and spotted on weathered surfaces.

A section (1212) from Rosehill shows the rock to be an olivine dolerite, with marked ophitic structure. The olivine has been altered either partly or wholly to a vivid orange-yellow pleochroic serpentine; in places, however, it is deep brown or pale green. The specific gravity of the rock is 2·985.

At Johnston's Leap the dolerite crosses the Sterk Spruit, which has cut a narrow gorge through the slightly inclined sheet. The dolerite is between 100 and 150 feet thick, finely columnar, and, like that at Rosehill, very coarse in character. On the right bank of the river (on the farm Coldbrook) the dolerite is covered with a thin layer of Cave sandstone.

The latter within a certain distance from the dolerite has been vitrified, and resembles a pitchstone in its black vitreous appearance. The vitrified rock passes insensibly into white quartzite, and is often veined and streaked with quartz, or else brecciated.

Under the microscope (1213) the rock shows a clear glassy groundmass, pale brown in colour, crowded with rounded to angular grains of clear quartz. It is evident that the felspar in the sandstone, together with some of the quartz, has been fused to form the clear glass. The quartz grains show corrosion borders, and round them are massed minute microlites of colourless material, probably newly-formed felspar. The microlites also build up aggregates with a granular appearance, sometimes forming a mass which possesses crystal properties, giving double refraction and straight extinction between crossed nicols. In the groundmass are minute colourless crystals of a mineral, which must be cordierite, with rectangular or hexagonal sections, and which are more abundant in some parts of the slide than others. Magnetite occurs in extremely microscopic crystals disseminated through the glass or enclosed in the larger cordierite crystals. There are also long needles of a pale yellowish green material, with very low double refraction. Zircon occurs in grains, sometimes in well-formed crystals, and is evidently one of the minerals in the sandstone which has escaped the fusion. The specific gravity of the rock is 2·42. The description by Mr.

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Harker* of a vitrified grit from the Island of Soay, off the west coast of Scotland, fits this rock from Barkly East perfectly.

On this same ridge at Coldbrook there is a vein of black glassy rock in the dolerite much resembling a tachylite in appearance. It is well exposed near the top of the sheet, and varies in thickness from six to eighteen inches, and is apparently uniform in character throughout. Lower down the hillside it is not seen, owing to the covering of fallen material.

In section (1214) it shows a considerable resemblance to the vitrified sandstone just described.

The glass is a little browner in that, and shows perlitic structure, while there are a number of small vesicles filled with chalcedony and quartz.

In the glass are embedded grains of quartz, but fewer than in section (1213). These show corrosion borders and the same zone of microlites. Cordierite is absent, also the long needle-shaped mineral. Zircon is, however, abundant.

Whether this is a highly altered mass of sandstone or whether it is a vein of igneous material is uncertain. The mode of occurrence and general appearance of the rock favour the latter view; but in that case the quartz and zircon must have been derived from the Cave sandstone either from above or below. The density of the rock is only 2·403, and if this were entirely glass (without any free quartz), its density would be lower still, so that in composition the rock would approach a pitchstone, a rather curious type to find in the midst of a very basic intrusion. On the other hand, the resemblances to (1213) are great, but without a second examination of the locality the question of the actual nature of the rock must be left open.

The distribution of dolerites south of the Drakensberg has been described in the last Annual Report, but some of their petrographical characters are worth noting here.

The most characteristic type is the "spotted," very coarse ophitic dolerite, in which olivine is either absent or present in small quantity, the rock having a specific gravity of about 3·00. In some places biotite forms a characteristic accessory mineral—for example, in the dolerites just north of Cala (1117, 1118). In other places ilmenite occurs in large plates (1115), while the ophitic structure is not very marked.

A vein from a sheet of dolerite at Nyelasa, in the south of Xalanga, shows peculiarities in section (1112). There are large porphyritic labradorite crystals, with glass and augite inclusions set in a groundmass of felspar and augite. Crystals of augite occur, and as they become larger, tend to enclose the felspars ophitically, so that we get all stages of transition from the porphyritic to the ophitic type.

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* S. Harker. The Tertiary Igneous Rocks of Skye. Mem. of the Geol. Survey of the United Kingdom, p. 245, 1904.

The dolerite dykes in this area need some description, chiefly with regard to their distribution.

Dykes are more abundant in the upper divisions of the Stormberg series than sheets, while in the Volcanic beds they occur to the exclusion of the latter.

The commonest directions assumed by the dykes is either north-west to south-east or at right angles to that, but east and west or north and south dykes are not infrequent, while many of the intrusions curve very much. From a glance at figure 1, showing the directions of folding in this area, it is at once evident that the directions of the majority of the dykes is independent of the directions of folding, although there is much probability that the period covering the intrusions and the earth movements could not have been very long.

It was found in Elliot that the great dolerite sheets, as they cut through higher and higher strata, got gradually thinner, and pinched out in the Cave sandstone. A study of the dykes shows that they generally maintain the same width through a vertical range of several thousand feet, and penetrate the Volcanic beds in many places. Some of these dykes have been described petrologically already—for example, those on Middel Fontein and Sevenfontein—and it is noteworthy that they contain a small amount of glassy base, and are not holocrystalline, though the sections were always taken from the centres of the intrusions. The upward limit of these dykes is somewhere between 7,500 feet and 8,000 feet above sea-level, and there is no evidence that the molten material from them ever poured out over the uppermost surface of the Volcanic beds. Hence it is that around the Barkly Pass we find that the dykes and sheets never penetrate the bed of volcanic ash or the lavas above it. The same feature is pronounced at Rosehill.

To the north, however, as the base of the Volcanic beds, comes lower and lower, we find that dykes in them are numerous. Just above Siberia there is a very fine example of a dyke, which can be traced from near Dordrecht into Barkly East, cutting through all the beds now exposed, including at least 1,500 feet of volcanic rocks. A dyke which penetrated the lavas to an altitude of almost 7,800 feet was seen a little south-west of Rhodes. Around Lundean's Nek again the dykes, as a rule, do not penetrate the ash bed or the lavas, the altitude of the former being about 7,300 feet.

The evident deduction from these facts is that the intrusions of the dolerite dykes took place after the north-east, south-west folding.

With regard to the north and south folds, the evidence is not so satisfactory, but I think that the absence of dykes high up in the lavas in the synclinal troughs shows that the dolerites are earlier than these folds.

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Many of the volcanic necks are cut through by dykes or sheets of Karroo dolerite—for example, numbers 3 and 8 in Wodehouse and numbers 1, 3, and 9 in Elliot; possibly the intrusions have taken advantage of old lines of weakness. In one case, at least, number 7, near the Barkly Pass, in Elliot, it is probable that the dolerite has completely replaced the original material in the pipe. In section (1123) the rock is a typical ophitic dolerite, with a small amount of olivine and magnetite. There is a considerable amount of brownish glassy residue, with granules of augite and iron ore. The specific gravity is 2·935, and there can be no doubt that it belongs to the Karroo dolerites. The character of the intrusion, with its columns arranged vertically, shows in all probability that its extremity has just been denuded off, and that the molten material cooled against the basal ash bed seen at a slightly higher level a little to the north-east. Therefore the lavas would not be penetrated, which is in accordance with what has been noticed in the case of the Karroo dolerite dykes in the neigbourhood.

The age of the Karroo Dolerite intrusions can only be roughly determined. Seeing that they are later than the lavas, they must be younger than the Lias. In the Embotyi series of East Pondoland* again, boulders of Karroo dolerite are found in a conglomerate, probably of Upper Cretaceous age. Consequently the period of intrusion of the dolerites must be somewhere between Middle Jurassic and Lower Cretaceous.

X. The Later History of the Area.

With the cessation of the lava-flows we may consider the Stormberg epoch to terminate. Earth movements now commence to affect the beds, and the river systems were established, the whole surface of the lavas being traversed by streams and rivers, all actively engaged in the work of denudation.

A series of curving folds, convex to the south-east, produced undulations in the strata (see map, figure 1), and in the synclines thus formed the various tributary streams arose. Thus the direction of flow of the Kraai and the Orange Rivers was determined, also that of the small streams in the northern portion of the Elliot division, and in Maclear and Mount Fletcher.

At the same time, the watershed of the Drakensberg may have been produced, though the flow of the rivers towards the south and south-east would naturally only take place after the land surface in that direction had been depressed.

In the description of the dolerites it is shown that the intrusions probably took place immediately after these curved folds tilted the beds. The injection of molten material took place on a gigantic scale, and penetrate strata stretching from Natal to the western part of the Karroo.

* Ann. Rept. Geol. Commn. for 1901, p. 49.

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These Karroo dolerites form a perfect network of dykes, sheets, and laccolites, and belong to a single period of intrusion, for at no place does any one mass of dolerite cut another.

A second set of folds, with axes trending a few degrees east of north, then disturbed the strata, and are probably a little later in age than the dolerite intrusions.

These folds, though not altering the courses of the larger rivers, seem to have determined the direction of flow of a number of streams, mostly south of the present watershed. Such rivers are the Indwe, Xuka, and Bashee, and the reason may have been that previous to the folds the amount of water flowing southwards was insignificant, compared with the amount carried off to the Atlantic.

Mr. Schwarz has noted† that the irregular course of the Kenigha River in Matatiele is due to folding in a north and south direction. There are other rivers, too, on the north side of the watershed which flow in north and south synclines, *e.g.*, the Waschbank River and Kornet Spruit.

Owing to the cross-folding, we get rivers flowing along the dips produced by the compounding of these two sets of folds—for example, the various tributaries of the Kraai River, the Telle and Blikana Rivers, and lower part of the Xuka River.

At the same time a gradual elevation of the area went on, and the streams were enabled to erode the lavas rapidly. The elevatory action ceased, and the Kraai and Orange Rivers cut down to base-level, forming long flat valleys, over which the rivers wound in loops and bends. In this way the plateau or peneplain, around Rhodes, at an altitude of a little over 8,000 feet above sea-level, was formed.

A second elevation caused a cutting down by the rivers, and the 6,000-foot peneplain was carved out by the Kraai and Orange Rivers. The features of this peneplain have already been described in this report (p. 129).

The peneplain probably extended over what are now the valleys of the Holle Spruit and Waschbank River, possibly also into the Molteno division.

By the cutting up of the old plateau to form this peneplain the dykes of Karroo dolerite were exposed for the first time in this area.

Another period of elevation follows, and the gorges of the Kraai and Waschbank Rivers, Holle Spruit, Telle and Orange Rivers, etc., were cut back until an extensive peneplain was formed at an altitude of from 4,500 to 5,000 feet. This occupies all the low ground in Albert, Aliwal North, a part of Herschel and the Orange River Colony.

In many places the old river gravels still remain to indicate the nature of this flattish ground, but over most of the area the

† Ann. Rept. Geol. Commn. for 1902, p. 25.

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gravels are absent, or else a few scattered pebbles only testify to their recent removal.

This peneplain appears to have a very great extent, for Stow† has described gravels on the banks of the Kornet Spruit and Caledon River, in the Orange River Colony, and at a considerable height above the present river levels. A continuation of the upward movement caused the rivers to start cutting down vertically, and hence the Orange, Kraai, and Caledon Rivers flow in gorges usually several hundred feet below the general surface of the country, making irrigation from them almost impossible.

Gravels of this period occur at many points along the Orange River, and are evidently of comparatively recent age.

Mr. Alfred Brown, of Aliwal North, has obtained numerous fossils from these gravels, some evidently derived from the Burghersdorp beds, but others are contemporaneous.

Until his collections have been thoroughly examined, it is not possible to say whether the remains include any extinct types, or whether they are all those of forms existing at the present day.

From the gravels and from the surface soil he has also obtained numerous implements, both of rude and more finished types, some of which were buried at a considerable depth below the surface.

On the sea-ward face of the Drakensberg there are no well-marked plateaux or peneplains; probably, as Mr. Schwarz has suggested, the form of the mountain has been determined by the heavy rainfall, so that mere traces only of the old river plains would be left.

The high ground in the south of Elliot and Xalanga is evidently a portion of a plateau which reached an elevation of between 5,500 and 6,000 feet.

Farther to the south and south-east there is a stretch of flattish country around Engcobo and Umtata, which may represent another plain of river erosion.

† G. W. Stow. Report of the Geological Surveyor, Bloemfontein, 1878.

[NOTE.—For an account of the physical conditions under which the Stormberg beds were deposited and of the history of the elevation of this area, reference may be made to the paper "The Forming of the Drakensberg." Trans. S. A. Philosophical Society, Vol. XVI., part I., 1905.]

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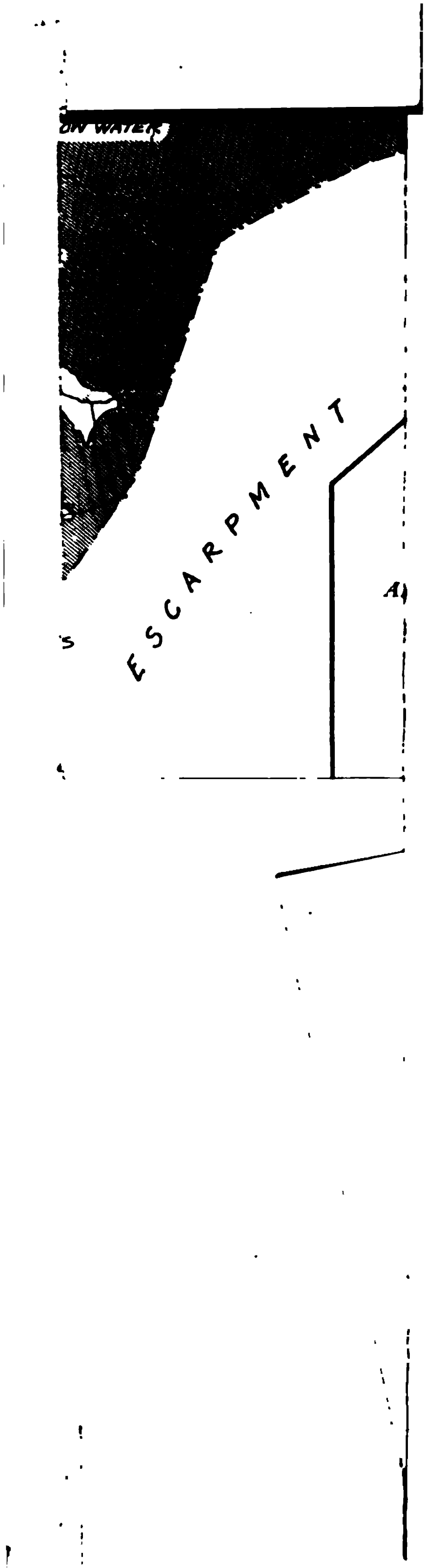

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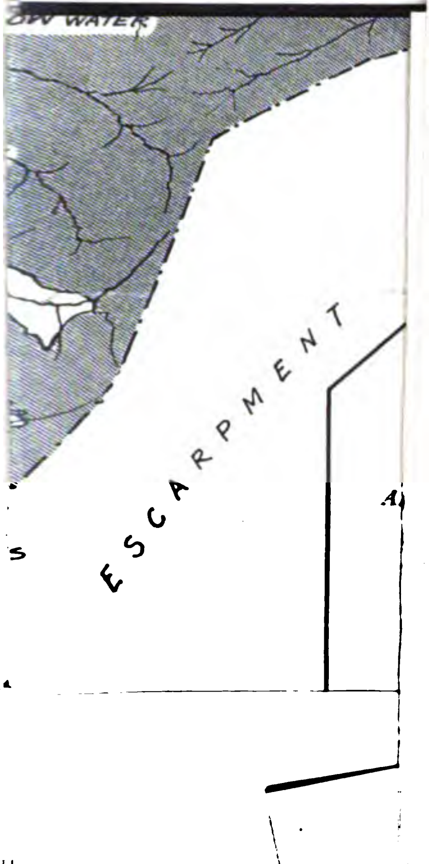

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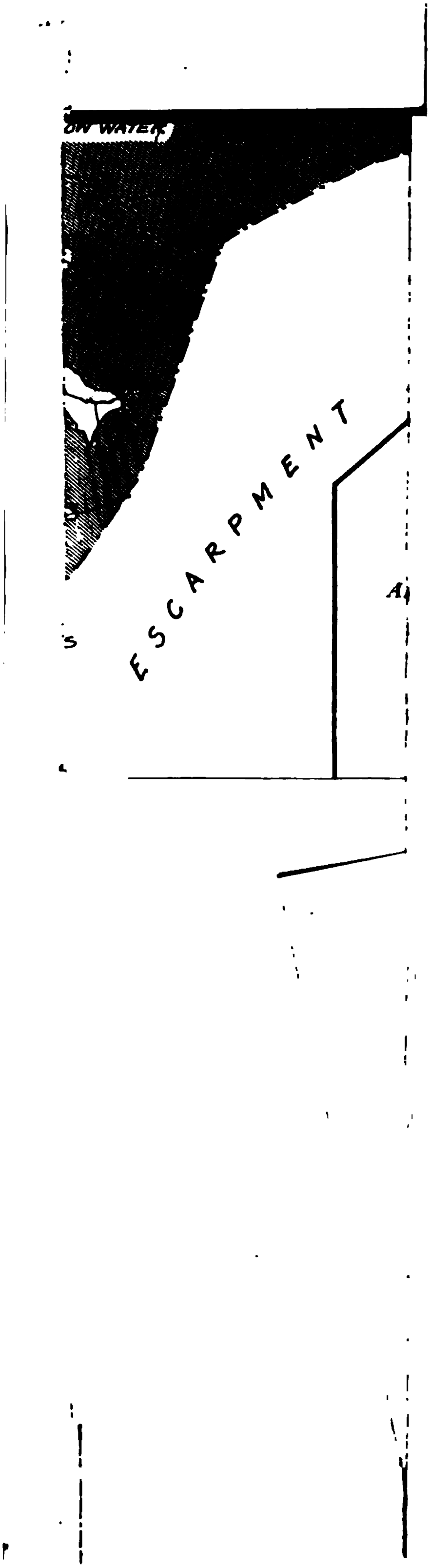

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CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

TENTH ANNUAL REPORT OF THE GEOLOGICAL COMMISSION.

1905.

Presented to both Houses of Parliament by command of His Excellency the Governor.

1906.

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1905

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Cape Town,
9th March, 1906.

The Hon.
The Secretary for Agriculture.

SIR,—

I have the honour to forward the Report and Annexures for the year 1905.

The work, as will be seen from the Report of the Director, has made steady progress; though the Commission have felt that it was incumbent on them during the present financial depression to avoid some expenditure which, though useful, could be postponed.

Any such curtailment of the work is a matter of great regret to the Commission, the members being of opinion that the practical value of the survey is such as to warrant increased expenditure instead of less.

It is gratifying to have to record that on several occasions the services of the staff have been requisitioned to advise on the geological conditions of sites selected for municipal reservoirs. The Commission have to express their thanks to the Directors of the S. A. Kerosene Oil Shale Syndicate, Ltd., for permission to investigate the alleged discoveries of Oil Shale at Loeries River, and for the assistance afforded on that occasion.

During the year the staff has been weakened by the resignation of Mr. E. H. L. Schwarz, who has joined the staff of the Rhodes College at Grahamstown During a service of 9½ years on the staff of the Survey, Mr. Schwarz proved himself an able and intelligent geologist, and the Commission feel sensible of the loss experienced and desire to record their sense of the value of Mr. Schwarz's work.

The forthcoming publication of a Coloured Geological Map of a considerable section of the Colony will, it is hoped, meet a growing demand for information of this nature.

I have the honour to be,
Sir,
Your obedient Servant,
JOHN X. MERRIMAN,
Chairman of Commission.

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GEOLOGICAL COMMISSION.

DIRECTOR'S REPORT FOR THE YEAR 1905.

During the past year a larger area than usual has been mapped. Three geologists were in the field for from two to four months each in different districts during the first half of the year, and after Mr. Schwarz resigned, Mr. du Toit spent three and a half months in Vryburg and Mafeking, and I was in Hay for a similar period.

Through Mr. Schwarz's resignation the staff has been weakened by one third, but until an increased grant is obtained the work can be more satisfactorily carried on by two men than by three, for there is not sufficient money to provide transport and other facilities for three men.

Mr. Schwarz surveyed a strip of country along the coast between the George and Humansdorp Divisions, where the difficulties in unravelling the complicated geological structure of a disturbed region are increased by the presence of thick superficial deposits of comparatively recent date and by the forests. This area is of particular interest on account of the gold-mining carried on there to a small extent, and the possibilities of its further development. It will be seen that Mr. Schwarz comes to the conclusion that the gold-bearing quartz-reefs have not been fairly tested, and that some of the reefs should be worth mining. As to the banket beds there is as yet insufficient evidence of their gold contents. In Mr. Schwarz's Report there will be found much new information about the Pre-Cape, Table Mountain, Bokkeveld, and Uitenhage rocks, and an interesting description of the recent deposits in that unique part of the coast known as "The Lakes."

When I heard that Mr. Schwarz had resigned, I asked him to draw up an account of the area in Tulbagh, Ceres and Worcester surveyed by him in 1896. I did this because a summary only of this work was printed in the

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Annual Report for 1896, and it is desirable to have a longer description of this important area written by the geologist who first surveyed it. Mr. Schwarz most obligingly devoted about a month of his own time to preparing the account which is printed in this Report.

Mr. du Toit was occupied for three months in surveying an area continuous with his previous work in the north-east and lying to the south of it. This area includes the most important part of the only productive coal field in the Colony, concerning which Mr. du Toit has collected and systematised a large amount of information, and he has pointed out the directions most favourable for future development. He describes at some length the curved intrusions of dolerite between Queenstown and Indwe, of which very little was previously known.

During the latter half year Mr. du Toit commenced surveying that part of Bechuanaland which is included in the Cape territories, and his work has proved the existence of highly metamorphosed sedimentary rocks amongst the granite and gneiss; he also shows that the two formations are intercalated owing to the presence of thrust planes, and that the granite is not intrusive as regards these metamorphosed rocks. The latter are overlain unconformably by the volcanic and other rocks (Ventersdorp beds) which lie below the Black Reef beds. There are strong resemblances between some of the metamorphic rocks and the supposed western outliers of the Campbell Rand and Griqua Town series in Prieska, and I now believe that these ridges of magnetic quartzites, etc., in Prieska should be regarded as older than the rocks of the Doornbergen, though their relation to the gneiss round them may not be in all respects similar to that of the northern schists to the Bechuanaland gneiss.

This survey of Mr. du Toit's, in conjunction with mine in Hay, makes an important advance towards the joining up of the geological work done in the Transvaal with that done further south in Cape Colony.

In March I completed the survey of a small area left unfinished in the north of Malmesbury and the south of Piquetberg. From Porterville Road I went by rail to

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Riversdale, thence by road to Uniondale, examining especially some new railway cuttings, the recent deposits near Klein Brak River, and the marine Uitenhage beds on the Knysna estuary. From Uniondale I intended to go by road to the Coega Valley by way of the Baviaan's Kloof, Humansdorp and Uitenhage, but I was prevented from completing this general traverse of the large area surveyed during the past three years by Mr. Schwarz, and had to travel from Uniondale by rail. I was then occupied for over two months in mapping the country between the Zwartkop's River and the Zuurberg, from Enon on the west to Bushman's River. The report on parts of the Alexandria and Uitenhage would have been of more value had Dr. Kitchin's description of the marine fossils of the Uitenhage been available, but his work, which had to be stopped for want of funds a year ago, has only recently been taken up again. A feature of considerable interest in this district is the long line of volcanic rocks, both lavas and breccias, which accompanies the fault separating the downthrown Uitenhage beds on the south from the older rocks of the Zuurberg on the north. I also made an examination into the reported occurrences of oil-shale in the Loerie and Gamtoos Valleys. The reports were ill-founded, and no important results can be expected from the thin lenticles of lignite that have long been known from the Uitenhage beds.

After the Cape Town meeting of the British Association and the geological excursion to the southern Karroo were over, I left for Prieska, whence I crossed the Orange River to make a survey of the Hay Division. This work occupied me till the middle of December. The long drought north of the river made travelling impossible in certain parts of the district, and the absolute lack of veld along the river prevented me from connecting my work with that most interesting piece of country near Ezel Rand, surveyed in 1899. These unavoidable gaps in my map will be filled in during the coming season.

Asbestos digging gives occupation to a considerable and an increasing number of people in Hay; being independent of a larger water supply than that of the average farm, this work will certainly spread widely through

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the district if the market keeps up or improves, for the mineral occurs in several areas not yet worked. Diamond mining is carried on at the Peiser Mine, but the other minerals known to occur in the district, lead and copper ores and gold, have not yet been sufficiently proved for mining purposes. The Prieska railway has increased transport facilities, and there is room for hope that systematic prospecting under these more favourable conditions will bring to light payable ore deposits. There is no prospect, under present conditions, of the good hæmatite iron ores in the north of Hay being made use of.

The work in the Hay Division has proved that volcanic activity played a very important part in that area both before the Black Reef series was laid down, and after the period represented by the Griqua Town beds. Very good evidence was also obtained of the prevalence of glacial conditions in that country during the deposition of the uppermost part of the Griqua Town beds, a welcome addition to the accumulating evidence of cold climates in extremely remote ages. Unfortunately, no further information towards the correlation of these northern rocks with the established European and American Palaeozoic or older beds has been found.

The visit of the British Association in August was an event of no small importance to the Geological Survey. The discussion of many questions relating to South African Geology with geologists of wide experience in Europe and America, and the opportunities of taking them over some parts of the country, were very keenly appreciated, and were of material service to our work.

During the present year a coloured sheet representing the geology of the south-western corner of the Colony on the scale of 3·8 miles to the inch will be published, and it is hoped that other parts of the Colony for which the data are now ready will be similarly treated before long.

The description of Cape fossils collected by the survey has again been taken in hand; the marine mollusca of the Uitenhage beds are being dealt with by Dr. Kitchin, of H. M. Geological Survey, and the mollusca of the Umzamba beds (Upper Cretaceous) by Mr. H.

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Woods, of Cambridge; both of these works may be expected to appear during the year.

The Index to the first eight Annual Reports was issued early in the year to those institutions and persons to whom the Reports were sent.

The following papers by members of the staff have appeared in the Transactions of the South African Philosophical Society:—

"The Glacial Conglomerate in the Table Mountain Series near Clanwilliam," by A. W. Rogers.

"The Rocks of Tristan D'Acunha, etc." by E. H. L Schwarz.

"The Forming of the Drakensberg," by A. L. du Toit.

"The Volcanic Fissure under Zuurberg," by A. W. Rogers.

A. W. ROGERS,
Director of Survey.

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GEOLOGICAL COMMISSION.

General Abstract of Receipts and Disbursements for the Year ending 30th June, 1905.

	£	s.	d.
To Balance 1st July, 1904	64	6	0
„ Government Grant as per Treasury Drafts ...	2,000	0	0
„ Balance Account E. H. L. Schwarz	12	10	0
„ Cape Town Council Fees	7	9	10
„ Advances (current) repaid by Vouchers ...	132	0	0
	£2,216	5	10

	£	s.	d.	£	s.	d.
By Salaries	1,300	0	0			
„ Allowances, Personal	300	11	9			
„ do. Horse	23	19	0			
„ do. Cycle	3	13	0			
„ Railway Fares	36	3	3			
„ do. Carriage and otherwise ...	18	15	10			
„ Cart, Horse hire, Transport	43	7	0			
„ Postages	13	17	2			
„ Printing Annals, Reports, etc. ...	47	1	10			
„ Books, Magazines	7	12	9			
„ Analyses...	2	16	0			
„ Description of Specimens	60	0	0			
„ Specimen Rock Sections	8	4	6			
„ Compass, etc.	5	9	3			
„ Horse Purchase Loss	20	10	0			
„ Shipping Charges	4	15	8			
„ Wages, Clerical	1	10	0			
„ Furniture, etc.	3	12	6			
„ Miscellaneous	8	5	5			
„ Cape Town Council Fees paid to Staff	13	15	10			
				1,924	0	9
„ Advances made				132	0	0
„ Balance				160	5	1
				£2,216	5	10

I certify that the above Account has been checked and compared in this Department with the Books and Accounts, and has been found to be satisfactory.

WALTER E. GURNEY,
Controller and Auditor-General.

Cape Town, 26th February, 1906.

THEODORE MACKENZIE, Secretary.

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GEOLOGICAL SURVEY

OF

PARTS OF THE DIVISIONS OF UITENHAGE

AND ALEXANDRIA.

BY

A. W. ROGERS.

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CONTENTS.

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GEOLOGICAL SURVEY

OF

PARTS OF THE DIVISIONS OF UITENHAGE AND ALEXANDRIA.

By A. W. Rogers.

The area surveyed in the Divisions of Uitenhage and Alexandria lies south of the Zuurberg range and between the Bushman's and Zwartkop's Rivers; it includes that part of the Sunday's River valley which lies below the junction of the Bezuidenhout's River.

Topographical Features.

The Zuurberg range, which bounds the area on the north, is formed by a group of rounded or flat-topped ridges, trending about east-south-east. They reach a height of 3,244 feet at the beacon, which is placed a few miles north of the limit of the accompanying map.

The contrast between the shape of the Zuurberg range and of the mountains (Great Winterhoek and Elandsberg) in the west of Uitenhage is very great; the latter rise into high peaks, and are greatly serrated, features that are not seen in the gently-curved surfaces of the Zuurberg.

Another contrast, that between the surface of the range and the precipitous valleys cut into it, is remarkable; the valleys of the streams draining the south flank of the Zuurberg have steep grades and very steep sides; precipitous sides also characterise the poort of the Bushman's River, which drains a wide area north of Zuurberg, and traverses the range near Alicedale Junction.

The southern foot-hills, which form a belt about three miles wide, intervene between the main range and the country formed by the Addo Hills and the valleys of the Sunday's and Bushman's Rivers. The foot-hills have rounded summits like those of the main range, but they do not reach the same height.

Longitudinal valleys separate the foot-hills from the country to the south. The Addo Hills lie between the Bushman's and Sunday's Rivers; they are gently sloping, broad hills, with occasional precipitous declivities flanking the two rivers. Their greatest height is about 1,300 feet. On the left bank of the

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Sunday's River the ground rises steeply to the Grass Ridge, a country similar to but lower than the Addo Hills. Between the Coega and Zwartkop Rivers there is a similar tract, called Grass Ridge in the west, and Amsterdam Flats near the coast. The slopes in this country between the foot-hills and the coast are even now largely covered with dense bush, particularly in the Addo Hills, but the hilltops are usually grassy. The southern slopes of Zuurberg and the foot-hills are clothed with forest.

The Sunday's River runs across a wide alluvial plain below the confluence of the White River, and a continuously increasing area in this plain is being brought under irrigation, chiefly by water raised from the river by pumps.

The coast is sandy, and the sand belt reaches a width of over two miles near the mouth of Sunday's River.

At the time of my visit, the Sunday's and Bushman's Rivers alone had water in them, as the great kloofs draining the Zuurberg range were dry.

Geological Structure of the Area.

The Zuurberg range is made up of rather closely-folded rocks, belonging to the Witteberg group; on each flank higher beds, the Dwyka series, come in,[1] though on the south the Dwyka beds are cut out by a fault east of Thornleigh; the range is thus a complex anticline. The strike of the rocks is about E. 10° S. The southern boundary is a fault, along which the Uitenhage beds are thrown down against the older rocks to the north of them. From Duncairn westwards, as far as Enon, a strip of volcanic rocks intervenes between the Uitenhage beds and the older rocks along the fault; from the evidence hitherto obtained, the age of the volcanic rocks must be the same or less than that of the fault, *i.e.*, post-Uitenhage (Lower Cretaceous).

South of the fault nearly the whole of our area is built up of the Uitenhage beds, though these rocks are concealed over wide areas by various thicknesses of comparatively recent limestones, sands, pebble beds, and alluvium.

At Coega Kop an inlier of quartzite, which probably belongs to the Table Mountain series, projects through the Uitenhage beds. It lies on the line connecting St. Croix Island with the Great Winterhoek Mountains, and is doubtless a peak rising from a buried ridge continuous with the Great Winterhoek range.

The recent work in the Sunday's River Valley has not made it necessary to modify seriously the statement in the Report which first dealt with the area,[2] that "the Uitenhage Series in

[1] Pinchin, Q. J. G. S. XXXI. 1875. p. 106.
[2] Ann. Rep. Geol. Com. for 1900, p. 16.

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this district appears to form a shallow syncline, of which we saw one limb along the Zwartkop's River, and the other limb between Enon and Wolve Kraal, in the Sunday's River valley. The axis of the syncline lies between north-west and west-north-west." The northern limb really lies between Enon and Sandflats. The syncline is not symmetrical; the northern limit is greatly affected by the fault along the Zuurberg, while no corresponding feature has been noticed near the Zwartkop's River, and the low dips seen in the exposures of the lower part of the series in that neighbourhood make it probable that a similar southern fault does not exist. In the valleys of Sunday's and Coega Rivers the dips are low, and they vary considerably in direction within short distances.

It is not yet possible to map the marine Uitenhage beds according to fossil zones, though enough is known to show that the beds characterised by certain fossils, if these are on one and the same horizon throughout, do not maintain the same lithological characters over the area examined.

The recent marine beds occupy the tops of the hills over the greater part of the area south of the foot-hills of Zuurberg, and they lie flat on the old surface cut through the Uitenhage formation.

The gravels and alluvia of fluviatile origin lie at various levels below the recent marine beds.

The Table Mountain Series.

The white quartzites of Coega Kop, which probably belong to this series, dip at about 70° to N. 25° E. They have a great similarity to much of the rock belonging to this group west of Uitenhage town.

The rock called St. Croix Island, which lies in Algoa Bay, about four miles from the mouth of Coega River, is probably made of the same rock,[1] and the same can be said of Jahleel and Brenton rocks, near St. Croix, but I had no opportunity of visting the islands.

On the farm Balmoral a group of warm water springs issues from a low hill, of which the rocks are covered up with soil and a ferruginous rock deposited by the spring water. One of the springs, however, issues from between two large masses of quartzite, which appear to be in place, and resemble the quartzite of Coega Kop. The spot lies near a line drawn from the islands through Coega Kop to the Winterhoek range.

[1] According to Dr. Rubidge, quoted by Stow, "The Geologist," 1861, p. 238.

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THE WITTEBERG SERIES.

The Bokkeveld beds do not crop out within this area, though they almost certainly lie under the Uitenhage beds of the Grass Ridge.

The Witteberg beds are seen in the Zuurberg. They comprise quartzites, slaty shales, and sandy slates. The quartzites make great outcrops in the steep valleys draining the mountains, but the shales are rarely seen, except on the roads and railway cuttings. The shales have, however, afforded zones of slight resistance to the streams, and their presence is marked by the steep-sided longitudinal valleys which are a striking feature in that part of the Zuurberg lying between the White River valley and Bushman's River.

The beds are very much folded. Between the south end of the Zuurberg Pass, on Rockwood Estate, and Melkhout Boom there are at least two great anticlines and synclines, with limbs dipping at angles of from 50° to vertical; but there is a great amount of folding on a smaller scale, affecting the limbs of the great folds. The smaller folds scarcely influence the thick bands of quartzite, which reach a thickness of several hundreds of feet; but those portions of the series made up of thin quartzites, interbedded with shales, or shales alone, are often intensely crumpled, as may be seen in the railway cuttings between Sandflats and Alicedale Junction, especially near Bellevue, and in the Bushman's River Poort, near Alicedale.

The strike of the rocks is about 10° south of east on the average.

THE DWYKA SERIES.

From Duncairn in the east to Enon on the west, the Witteberg series is followed to the south by a considerable thickness of greenish and grey shales, whose position proves them to be the Lower Dwyka shales. They are well exposed on the road leading to Zuurberg Pass from Coerney. They usually dip vertically, or at a high angle southwards, or towards S. 10° W. At one spot, on Buffels Kuil, on the right bank of Coerney River, the Lower Dwyka shales dip at a high angle (80°) northwards under the Witteberg beds, and the same dip is seen in the Witteberg beds there, so the rocks are overfolded.

The Dwyka boulder beds have the characters usual to the formation in the south of the Colony. It is a dark, blue-grey rock, with large and small rounded and sub-angular fragments of various rocks in it. These rocks include granite, gneiss, diabase compact and amygdaloidal, quartzites, grits, hard shales, and dark limestone. When the matrix is weathered, just at the top of the steep hill on Rockwood Estate, by the roadside, for example, well-striated boulders can be obtained without difficulty; elsewhere the boulders are difficult to break out.

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The thickness of the boulder beds is quite 1,000 feet, and there is no reason to believe they are partly or entirely reduplicated by folding between Thornleigh and Enon, where each stream flowing south from Zuurberg has cut a deep gorge through the series.

The Upper Dwyka shales were found between Honey Vale and Kremlin; both to the east and west of this strip of country they have been cut out by the fault. The black shales (" white band ") are exposed in a small quarry on the road up to Zuurberg, and above these beds there are green shales, thin limestones with fibrous structure, and thin layers of dark chert. These beds are greatly twisted and broken. They are well seen in roadshide quarries and in the water sluit on the road to Zuurberg.

THE UITENHAGE SERIES.

In the Annual Report for 1900, the classification of W. G. Atherstone was adopted for the area between Uitenhage and Geelhout Boom (Dunbrody), on the Sunday's River, with little alteration. It is as follows:

Uitenhage series.	Sunday's River beds. Enon beds. Wood beds.

In the same Report it is shown that this succession is not a strictly chronological sequence over the whole area then known, for strata with marine fossils usually found in the Sunday's River beds are interbedded with red marls and shales, and are overlain by conglomerates like those of Enon in the hill north of the Uitenhage Location. Additional evidence for this conclusion has been obtained during the recent continuation of the work in the Uitenhage district. In spite of this proof that the three divisions into which the series is usually separated are really contemporaneous deposits to a certain extent, so that, except where one member can be proved to overlie another, the lithological nature of either is not a precise guide to its age, it is necessary to retain the three names at least for the purpose of describing the district; and as no large palæontological distinctions, other than that due to the prevalence of marine or fresh-water conditions, have yet been drawn between successive groups of strata, no better classification can be adopted at present.

The fossils from the Sunday's River beds, collected in 1900 and during the past year, have not yet been examined in detail, though the work is now in progress. In the present Report, therefore, the names given to the fossils are those used by

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Tate,[1] with a few corrections kindly given me by Dr. F. L. Kitchin, of H.M. Geol. Survey, who is making an examination of the fossils.

THE ENON BEDS.

The conglomeratic rocks and the sands and marls interbedded with them are only developed along the northern edge of the area of Uitenhage beds.

Between Slagboom and Enon village there are excellent cliff sections through the conglomerates along the White River. The prevailing colour of the rocks is red, but near Enon village their colour is nearly white. These white rocks are like the white conglomerate of Honing Nest Kloof in Mossel Bay, and the "White Enon" of Willowmore. In the latter district, Mr. Schwarz found that the red conglomerate lay below the white,[2] but in the Uitenhage and Alexandria area the white conglomerate does not appear to form a definite band of rock, for it is not seen on the south of the Slagboom hills, nor in the Coerney River sections, nor in those along the road to Zuurberg Pass from Coerney Station, nor in the neighbourhood of Sand Flats.

On the White River the conglomerate is made of well-rounded and sub-angular pebbles and boulders up to about eight inches in diameter, though the small pebbles are by far the more abundant. In places there are sections from 50 to 100 feet in height cut through the conglomerate, and these show that there is very little sand interbedded with it. The pebbles are often so numerous that they are in contact, and in such a case adjoining pebbles are frequently broken by having been crushed against each other. Neither in these sections nor further east did I find polished pebbles in the conglomerate.

The width of the conglomerate belt is greater near Enon than anywhere between that place and Bushman's River, and it forms a strip of country, about four miles wide, though there are considerable thicknesses of sandy shales and slightly calcareous shales included in this measurement. It is impossible to lay down a consistent boundary line between the Enon beds and the overlying Wood beds throughout a large area, and the apparent absence of fossils from the country between Enon and Sand Flats, probably due to lack of outcrops, prevents the succession there from being compared with the Bezuidenhout's and Sunday's River sections. The only guides to mapping the Enon beds, as distinct from the Wood beds, in this area, were the number of pebbles in the soil and the colour and character of the

[1] Tate, R. On some Secondary Fossils from South Africa. Q. J. G. S. XXIII, 1867, pp. 139-175.

[2] Schwarz, Ann. Rep. Geol. Comm. 1903, pp. 112-113. The "White Enon" forms a definite horizon in the Oudtshoorn-Willowmore country, lying above red conglomerates which are at the base of the formation.

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latter. Pebbly and reddish sandy soils are characteristic of the Enon areas, and clayey, pale-coloured soils are found in the areas occupied by the Wood beds and Sunday River beds.

The pebbles are chiefly of quartzite and hard sandstone; vein quartz is fairly frequently met with; slaty rocks are rarely seen between Enon and Sand Flats; Dwyka pebbles seem to be entirely absent in the exposures I examined, and there were no granites or other igneous rocks found, nor schists.

On the Zuurberg Pass road the conglomerates are exposed in a roadside quarry, where the matrix is more clayey and less sandy than at Enon. In the Coerney River valley, the conglomerate is seen in a cliff section on the right bank; it is a red rock, with abundant pebbles.

East of Duncairn, on Zand Vlakte and De Bruyn's Kraal, the strip of conglomerate between the Witteberg quartzites and the clayey rocks of the Uitenhage series is very narrow; in this neighbourhood the older rocks are concealed by the comparatively recent sands and marine limestones, but information got from old wells east of the railway proves that the conglomerate does not extend half a mile south of the quartzites, at least within 30 feet or so from the surface.

In places where the conglomerate is thick-bedded, and where no lenticular layers of sand are exposed, it is difficult to determine the dip, but the dip of the strata on White River, the Zuurberg road, Coerney River, Mimosa, the Waggwa road, and on the road from Sand Flats to Bellevue are above 20° to the southward, generally a few degrees west of south, at some places, as on the east end of the Enon ground, nearly south-south-west, and at others (Coerney River and Waggwa) about 10° east of south. Where a series of observations on the same line across the strike of the rocks can be made, as on the road to Zuurberg, and down the Coerney valley, the dip decreases southwards, and is under 10° at distances of three miles or more from the northern boundary of the series. The deep borehole at Sand Flats proves that conglomerates comparable to those of Enon do not occur within 1,500 feet of the surface, though a band of "coarse grey sandstone, containing pebbles,"[1] four feet thick, was passed through at 611 feet, and fifteen feet of "soft grey sandstone, containing water-worn pieces of brown shale,"[1] were met with at 809 feet. The borehole is about $1\frac{1}{2}$ miles from the nearest outcrop of quartzites to the north.

The explanation of the rapid disappearance of the conglomerates eastwards, and the high southerly dips along their northern limit, is evidently that there is a strike fault, with southerly downthrow, on the northern side of the area. The throw appears to increase eastwards, and is probably at its maxi-

[1] Taken from the record of the bore-hole kindly furnished by the General Manager of Railways, and summarised below, p. 18.

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mum between the railway near Sand Flats and the Bushman's River. The further course of the fault towards the east has not yet been investigated.

The fault explains the remarkably straight northern boundary of the formation, and the apparently very steep angle at which the Witteberg quartzites disappear under it.

In the Coega valley there is a considerable development of beds without marine fossils, but the only locality where there may be conglomerates of the Enon type in the valley is Balmoral, on the hill from which the mineral springs issue. I am inclined to think, however, that the pebbles which gave rise to the suspicion that Enon beds are present come from the raised beach or river gravels of rather more recent date.

The Wood Beds.

The typical occurrence of this division of the Uitenhage series is along the Sunday's, Bezuidenhout, and White Rivers, in an area which lies just outside that dealt with in this Report, and though the beds must be present, judging from a stratigraphical point of view, south of the conglomerates just described on the flank of the Zuurberg, none of the characteristic fossils were found. There are also certain beds in the Coega valley which apparently pass beneath the marine beds of Sunday's River, and which may be placed in this group.

The Wood beds are not well exposed between Enon and Bushman's River. The small outcrops of marls, shales, and pale-coloured loose sandstones, seen along the roads and a few of the streams, do not afford the opportunity for fossil collecting that there is in the extensive river sections near Dunbrody. The thickness of these rocks between the Addo Hills and the conglomerate to the north must be considerable, but their upper limit is as ill defined as their lower limit (see p. 21). It is certain that the Sunday's River beds, with their marine fossils, take a large part in the structure of the Addo Hills, for they are seen to pass with a low north-easterly dip into the hills from their outcrops on the left bank of Sunday's River, below Barkly Bridge. Rocks corresponding to these marine beds have not been seen on the northern slopes of the Addo Hills, and no useful information was got from the few wells and boreholes on the hills. From wells south of Sand Flats, I was told that shells had been obtained, but the specimens had been lost, and in only one case was it possible to conclude from the information that the shells came from the recent or sub-recent marine deposits which overlie the Uitenhage beds in those parts.

I was told by the foreman in charge of the machine at the deep hole at Sand Flats that a shelly layer had been passed through at 400 feet, but no shells had been kept. As it is

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stated on the record[1] that the rock from 338 to 430 feet was "red shale," it is unlikely that the shelly layer belongs to the marine beds, for so far as the survey has been carried, the beds containing marine fossils are never red; though there may here be an intercalation of marine beds, as at the Uitenhage location.

The Sand Flats borehole passes through shales, marls, and sandstones to a depth of about 1,500 feet, when the boring was stopped. The thin conglomerates have already been referred to (p. 17), but they are quite insignificant features. The full record of the borehole, as kept by the foreman in charge, can be seen in the Reports of the General Manager of Railways for the years 1903 and 1904. There is no reason to doubt the determinations of the great bulk of the rocks taken from the hole, for I was able to compare the lowest 200 feet of the core with the record, and found it correct; but there are 6 inches of dolerite recorded from a depth of 1,086 feet, and from experience of other records, wherein the name dolerite is given to hard dark rocks of sedimentary origin, it is impossible to accept the determination in this instance without seeing that portion of the core on which the statement was based. No intrusions of igneous rocks are known in the Wood beds or in any other part of the Uitenhage series in this area, and although it is possible that the "dolerite" recorded is an offshoot from the volcanic belt to be described later, this is not likely, for the volcanic rocks, as seen at their outcrops and in a well, are very different in appearance from the rocks known as dolerite to foremen who have bored in the Karroo region.

The water from considerable depths in the borehole is too salt for use. This salt is derived from the strata pierced below the 800 feet level, for fresh water is obtained above that level, and the surface wells sunk in the recent marine beds in the neighbourhood are not salt.

Along the Coega River, the marine beds of the Sunday's River group crop out on the left side of the valley from the farm Grass Ridge No. 2, down to the mouth. Below these beds there are shales, marls, sandstones, and thin layers of conglomerate, which lie about horizontally or with a slight north-easterly dip. These lower beds do not contain marine fossils, so far as we know at present, and they can be placed more naturally with the Wood beds than with either of the other two divisions of the series, though there is little reason to consider them strictly contemporaneous with the Wood beds of Dunbrody.

On the north side of Coega Kop there are hard brown and grey sandstones, with impressions of lignite and occasional "clay galls" or pellets in them, lying almost horizontally, and evi-

[1] "Report on Water Boring on the Cape Government Railways for the year ending 31st December, 1903." G. 66, 1904.

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dently abutting against the Table Mountain quartzites of the Kop, without the intervention of any considerable mass of breccia or conglomerate. The exposures are not good enough to show the nature of the rock as far as the junction with the quartzite, but there is little room for a change in the rock.

This stone is being quarried for building purposes, for which it appears to be well suited, though the colour is rather dark. It covers but a small area, unless it extends underneath the soil on the other sides of the Kop. It resembles some of the Oudtshoorn sandstones and the rock at Cape St. Blaize more than any other part of the Uitenhage series in this district.

Marls and loose sandstones crop out at intervals up the Coega valley. On Welbedacht's Fontein, on the left bank of the river, near the south-east boundary fence of the farm, there is a good section, showing about 33 feet of these beds. The rocks seen are:—

Recent	Soil and sub-soil	3	feet	0	inches.
	Coarse river gravel	2	„	0	„
Wood beds of Uitenhage series	Red shale	1	„	6	„
	Green marlstone	0	„	6	„
	Red marl	2	„	0	„
	Green marlstone	0	„	3	„
	Red marl	4	„	0	„
	Greenish sandstone	2	„	0	„
	Red marls, with thin partings of green marl, irregularly bedded	18	„	0	„
	Greenish sandstone, with lignite and a few quartzite pebbles	4	„	0	„

The lowest rock is the only one in which any trace of fossils was seen, and the lignite and indistinct impressions of fragments of plant stems found in this rock cannot be determined. Some parts of the sandstones are calcareous; the calcite forms large crystals, enclosing the grains of sand and mutually interfering; large cleavage faces of the calcite are seen when these patches of rock are broken. Gypsum occurs along surface of joints, sometimes filling up the cracks, but I saw none in layers in the rock nor in crystals distributed through it. The red marl and the green marlstone is very like some of the rocks seen in the outlier of Uitenhage beds, through which the Doorn River valley near Heidelberg is cut.

On the farm Balmoral a borehole was put down in the Coega valley to the depth of 200 feet, without reaching the bottom of the Uitenhage series. Those parts of the core kept by the owner (Mr. Hartmann), and shown to me, were rather loose sandstones and marl. Pieces of lignite were not infrequent, and thin layers of that material, half an inch thick, were passed through.

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On Welbedacht's Fontein a borehole has been sunk near the bottom of the valley, some distance up-stream from the section described above. I am indebted to Mr. Ritso, engineer in charge of water-boring, for a copy of the record of the hole, which is of considerable interest, for it proves that 300 feet of sandstones and shales, without thick beds of conglomerate, underlie this part of the valley.

The record gives:—

Surface	to 28 feet...	clays, with pebbles.
28 feet	„ 46 „	shale.
46 „	„ 76 „	shale and sandstone.
76 „	„ 86 „	laminated shale.
86 „	„ 98 „	sandstone.
98 „	„ 144 „	shale.
144 „	„ 150 „	sandstone.
150 „	„ 228 „	shale.
228 „	„ 234 „	sandstone.
234 „	„ 262 „	shale.
262 „	„ 272 „	sandstone.
272 „	„ 300 „	shale.

The distinction drawn between shale and laminated shale probably means that the "shale" is a marly rock, with ill-defined lamination, such as is seen in the natural sections in the neighbourhood. No fossils are noted in the core.

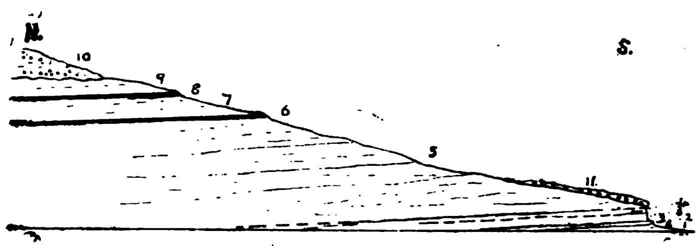

FIG. 1. Section drawn from the Coega River northwards to the plateau on Zwart Koppen. Scale $\frac{1}{10}$ inch to 10 feet.

1. Grey marl.
2. Thin grey limestones.
3. Greenish marl.
4. Greenish sandstone.
5. Grey shales, marls and clays.
6. Hard sandy limestone with *Exogyra*.
7. Grey shales, etc., with Arca.
8. Limestone with *Trigonia*, *Pleuromya*, *Arca* and *Exogyra*.
10. Marine beach deposits, limestone, pebble beds.
11. River gravels.

On the left bank of the river on Zwart Koppen, about a mile above the main road drift, there are several exposures from the river bed up to the top of the plateau, covered with recent marine beds. The section (fig. 1) represents the succession of rocks at this place. The loose sandy beds and the marls resemble rocks seen further up the valley. The thin limestones in the lower

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part of the section are like those seen in the bed of Sunday's River near Dunbrody, and they contain small pieces of lignite and indefinitely shaped fragments of leaves. Some clayey limestone with these beds has cone-in-cone structure. On the slopes above the low cliff on the river bank there are clays interbedded with thin sandy limestones containing marine fossils, viz., *Cucullaea jonesi*, Tate, *Exogyra imbricata*, Krauss, *Pleuromya lutraria*, Krauss, and *Trigonia herzogi*, Hausmann.

On the right side of the valley, where the road to Port Elizabeth leaves it, there are brown marls with a very few marine shells; the only one I could see well enough to name was a small *Cucullaea*, like *C. jonesi.* Immediately above this marl there is a bed of loose yellowish sandstone, and a similar rock without fossils is exposed in a gully between the main road and the railway. This sandstone must lie below the marls containing *Cucullaea*. Below the railway, on the right-hand shore of the vlei, there are green and grey marls without fossils.

The general dip of the beds in the Coega valley is towards the north-east at a low angle. The dip of the Sunday's River marine beds in the Zwartkop's valley is in the same direction, so if this dip is persistent and if the rocks are not faulted, the marine beds must pass below the Wood beds of the Coega valley, and these in their turn below the marine beds of Sunday's River valley. This is extremely improbable, because the marine beds of Zwartkop's and Sunday's Rivers are very much alike, both lithologically and in their fossil contents, so there must either be a fault, with southerly downthrow, running nearly parallel to the Coega valley and lying south of Coega Kop, or there must be an anticlinal fold between the two valleys. There is no direct evidence at present as to which of these views is correct, but the fault would evidently be a repetition on a small scale of the fault south of Zuurberg. The only visible fault in the Coega valley is seen on the left bank below Welbedacht's Fontein; it has a south-easterly trend, and the rocks are thrown down on the north-east side for a distance of about five feet only. If there is a fault south of Coega Kop its southerly throw may be about 500 feet; the displacement cannot be much less if there is no change of dip in the marine beds to the south.

THE SUNDAY'S RIVER BEDS.

(a) In the Coega Valley.

(A)[1] The section on the left side of the valley showing the upward passage from the supposed Wood beds, which do not contain marine fossils, into marine beds with *Trigonia herzogi*, *Pleuromya lutraria*, *Cucullaea jonesi*, and *Exogyra imbricata*

[1] The annexed map shows the positions of the sections indicated by capital letters.

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has already been described, and the occurrence of a small *Cucullaea* in the marls on the Port Elizabeth road was also mentioned (p. 22). These beds are the lowest which contain marine fossils, and are exposed in the Coega valley. Whether these beds are later than the Wood beds containing *Psammobia atherstonei*, *Pecten*, *Ostrea*, and other marine forms at Dunbrody, it is impossible to state.

There are many exposures of the Sunday's River beds on Grass Ridge No. 1, but they have not been thoroughly searched. The following were seen there:—

Gervillia dentata, Krauss.
Exogyra imbricata.
Trigonia herzogi (small).
„ *tatei*, Neumeyr.

(B). In a kloof nearly a mile north of the hotel at Coega and about 100 feet above the railway station, there are clays, which are used for brick-making, interbedded with hard clayey limestones, from which these fossils were obtained:—

Cucullaca (Arca) jonesi, Tate.
Cyprina rugulosa, Sharpe.
Exogyra imbricata.
Gervillia dentata.
Modiola baini, Sharpe.
Pholadomya dominicalis, Sharpe.
Pleuromya baini, Sharpe.
Ostrea.
Trigonia herzogi (large and small specimens).
„ *tatei*.

These beds are on about the same horizon as those on Grass Ridge No. 1.

(C). In a kloof on the east side of the railway, about a mile up the line from Coega, shales and impure limestones are exposed. The fossils obtained here are:—

Olcostephanus atherstonei, Sharpe.
Astarte herzogi, Goldfuss.
Cucullaea kraussi, Tate (= C. cancellata, Krauss).
Exogyra imbricata.
Gervillia dentata.
Pholadomya dominicalis.
Trigonia conocardiiformis, Krauss.
„ *herzogi* (small).
Neritopsis? turbinata, Sharpe.

Olcostephanus atherstonei is especially abundant in a band of clayey limestone at this locality.

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(D). On the left bank of the river, about half a mile down from the railway, there are exposures of grey clays, shales, and thin limestones, containing:—

Olcostephanus atherstonei.
Corbula ? rockiana, Tate.
Exogyra imbricata.
Gervillia dentata.
Lima neglecta, Tate.
„ *obliquissima*, Tate.
Patella caperata, Tate.
Pecten projectus, Tate.
Pleuromya baini.
Sanguinolaria ? africana, Sharpe.
Trigonia herzogi.
„ *tatei.*

This section includes the beds seen at locality (C) and lower beds.

(E). One and a half miles down the valley from the railway there are grey clays and thin limestones exposed in scars on the steep slope on the left of the Coega estuary; these rocks contain but few fossils, amongst which are:—

Olcostephanus atherstonei.
Cucullaea (Arca) jonesi.
Exogyra imbricata.
Lima neglecta.
Ostrea.

(F). The highest beds seen in the streams which run into the Coega River are probably those exposed in the small kloofs on the west side of the main road to Grahamstown, about a mile and a half from the drift. At this locality were found:—

Cucullaea (Arca) jonesi.
Exogyra imbricata.
Pleuromya lutraria.
Trigonia herzogi (small).

(b) Sunday's River Valley.

This valley was examined from Buck Kraal to the mouth of the river. There are many localities in it which have been somewhat cursorily searched for fossils, but a thorough collection could not be made. The following are the chief places where fossils were obtained:—

(G). The river bed, Buck Kraal. For some 300 yards along the Sunday's River, near Mr. Robertson's house, there are good exposures of rock. The lowest beds seen are thin blue shales

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with large quantities of lignite in small fragments, but no recognisable plant remains were found. These beds are succeeded by false-bedded sandstones and thin layers of conglomerate, yellowish brown in colour, and about 20 feet thick in all; these sandstones do not contain many fossils, but *Trigonia herzogi* and *Psammobia atherstonei* occur in them. They are followed by shales, loose sandstones, and impure limestones in the form of concretionary lumps; the limestone nodules contain many shells, and these can be got in less abundance in the shales and sandstones. Gypsum occurs in cracks and isolated crystals in these beds. The whole section here is about 60 feet thick, and the fossils occur chiefly in the uppermost 30 feet. Those which can as yet be determined are:—

Hamites africanus, Tate.
Astarte herzogi.
Cardita nuculoides, Tate.
Cyprina rugulosa.
Pleuromya baini.
Psammobia atherstonei, Sharpe.
Trigonia herzogi (large and small).
Actaeonina atherstonei, Sharpe.
Turbo baini, Sharpe.

These beds lie above the plant beds of Dunbrody, including those with marine fossils, *Pecten* and *Ostrea*.

(H). The cliff behind Mr. Robertson's house on Buck Kraal is made of shales and thin limestones, evidently lying somewhat higher than the beds exposed in the river. They yielded:—

Hamites africanus.
Astarte herzogi.
Cardita nuculoides.
Pinna atherstonei, Sharpe.
Pleuromya baini.
Psammobia atherstonei.

For some distance below Buck Kraal the rocks are not well seen, and it is impossible to observe their dip, except at rare intervals. The next locality searched is at:—

(I). The cliffs on the right bank on Commando Kraal, where the following fossils were obtained:—

Astarte herzogi.
Gervillia dentata.
Ostrea.
Psammobia atherstonei.
Trigonia conocardiiformis.
" *herzogi.*

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Below this locality, where the beds dip at a low angle (less than 3°) towards north-west, the rocks are not seen again till the Addo outspan is reached[1]; the marls and sandstones on the right bank at this place seem to be unfossiliferous. There is an unconformity in this section; a thick bed of rather loose yellow sandstone lies across the denuded edges of a band of blue sandy clays below.

(K). For a distance of about 300 yards below Addo Drift, sandstones, shales, and thin limestones are exposed on the left bank of the river. Their thickness is about 20 feet. There is much lignite in small pieces in these rocks, and a considerable number of marine fossils, of which the following were determined:—

Cucullaea jonesi.
Exogyra imbricata.
„ *jonesi*, Tate.
Gervillia dentata.
Pecten neglecta.
Pleuromya baini.
„ *lutraria.*
Psammobia atherstonei.
Ptychomya complicata, Tate.
Trigonia herzogi.
„ *vau*, Sharpe.

Following up the road to Uitenhage, some good sections are seen between the river and the Toll-gate. They are chiefly shales and loose sandstones. Several of the outcrops of sandstones are covered with an incrustation of salt, which is sufficiently freely supplied to prevent the usual vegetation growing in the valley bottom at that place. This occurrence of salt is interesting in connection with the source of the salt in the Zwartkops Pan.

(L). Near the salt rock the following fossils were obtained from sandy limestone:—

Cardita nuculoides.
Cucullaea jonesi ?.
Exogyra imbricata.
Ostrea.
Ptychomya complicata.
Trigonia vau.

These beds probably lie about 100 feet above those at locality (K), and they pass under the rocks of Coega Kamma's Kloof and the northern part of the Grass Ridge, for they have a low southerly dip. The higher beds are not well exposed, but they appear on the tracks up to the Grass Ridge, and are greenish sandstones, shales, and hard shelly limestones. Pieces of fossil

[1] This and the next locality (K) are at the place called "Tunbridge's" in Atherstone's and Stow's papers.

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wood, of considerable size, like those found in the Wood beds of Paltje's Kraal[1] are not uncommon, but I could not make a collection of the shells, nor could they be well enough exposed for determination.

From the juncture of the stream in Coega Kamma's Kloof with Sunday's River, down to near the railway at Barkly Bridge, there are many exposures of clays, shales, and thin clayey limestones on the right bank of the river.

(M). On Zoet Geneugd there are precipitous cliffs, which are nearly 200 feet high. At the north end of the cliffs the section (Fig. 2) was obtained; in a steep kloof at this end of the cliffs

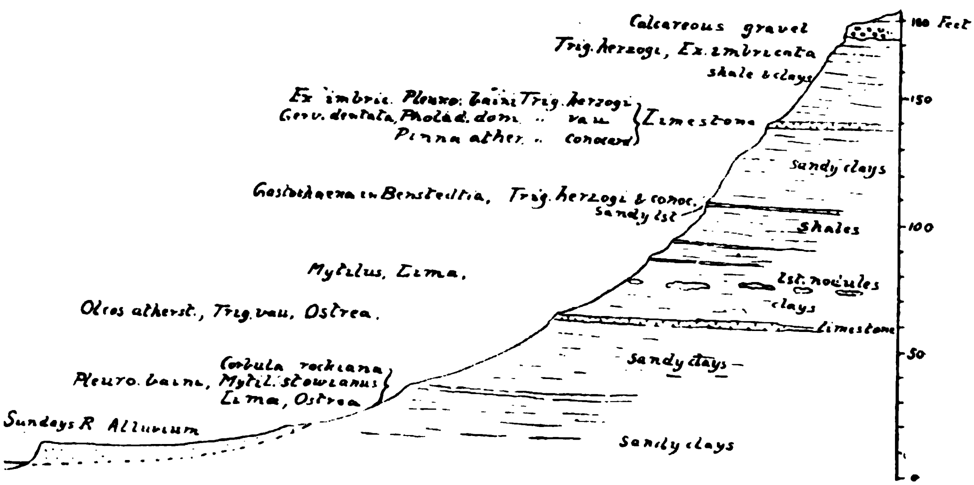

FIG. 2.—Section at the north end of Zoet Geneugd cliffs, on right side of Sundays River.

the individual beds can be examined for many yards along their dip; the face of the cliff is often too steep to work along, owing to the treacherous nature of the shale, but there are numerous steep gullies up which one can climb. The clays and shales are almost without shells, but pieces of lignite are not infrequently seen in them. The shells are confined to the harder layers, sandy limestones, limestones, and the nodules. Some of the limestone is spotted with bits of lignite, and closely resembles the limestone bands in the Wood beds at Dunbrody. The beds in this section include those in the lower part of the Uitenhage road, and they lie above the beds in the river below the drift; they are the lowest beds in the Zoet Geneugd cliffs, though their low southerly dip brings in higher beds very gradually, so that they form the greater part of the cliffs for a considerable distance down the river.

[1] Geol. Comm. 1900, p. 13.

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The figure (Fig. 2) shows the distribution of the fossils at the north end of the cliffs, and the following is a list of them:—

Olcostephanus atherstonei.
Corbula rockiana, Tate.
Exogyra imbricata.
Gervillia dentata.
Lima.
Mytilus stowianus, Tate.
Ostrea.
Pinna atherstonei.
Pholadomya dominicalis.
Pleuromya baini.
Trigonia herzogi.
   „ *conocardiiformis.*
   „ *vau.*
Gastrochaena dominicalis, Sharpe.
Benstedtia, (?) a plant.

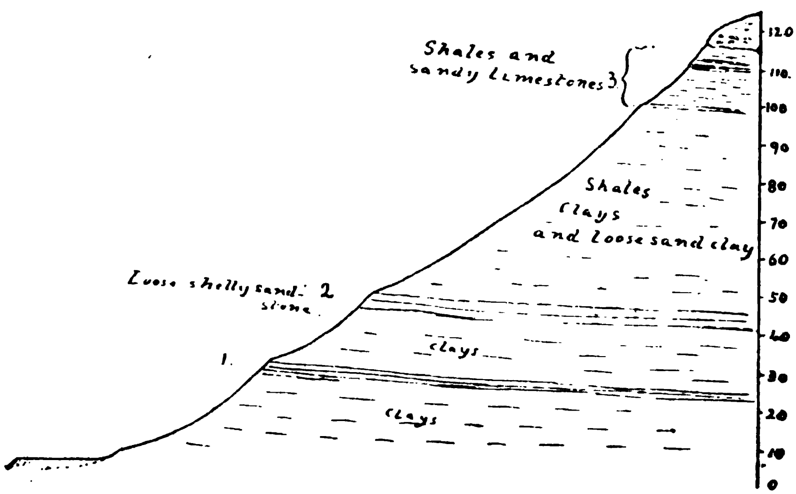

FIG. 3. Section through cliff on Eb-en-vloed.

A section taken from the broken cliffs on Eb-en-Vloed, just south of the Zoet Geneugd cliffs, will comprise the highest beds of the foregoing section and about 100 feet of the overlying strata. Fossils are more abundant at this spot (N) than on the Zoet Geneugd cliffs, and they seem to be very plentiful as far down as the exposures nearest Barkly Bridge.

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The section in Fig. 3 shows the beds from which the fossils in the following list were obtained:—

1. *Astarte herzogi.*
   Corbula rockiana.
   Cyprina rugulosa.
   Ostrea.
   Pinna atherstonei.
   Pleuromya baini.
   Trigonia herzogi.
   „ *conocardiiformis.*
   „ *vau.*
2. *Astarte longlandsiana*, Tate.
   Lima obliquissima, Tate.
   Trigonia herzogi.
   „ *vau.*
3. *Olcostephanus atherstonei.*
   Astarte herzogi.
   Corbula rockiana.
   Mytilus stowianus.
   Pleuromya baini.
   Trigonia herzogi.
   „ *conocardiiformis.*
   „ *vau.*
   Neritopsis ? turbinata, Sharpe.
   Turbo baini, Sharpe.

At the point marked O on the accompanying plan there is a particularly fossiliferous bed high up the cliff, and on a somewhat higher horizon than N. 3., but it does not extend far along the cliff in the same condition, it becomes more sandy and clayey, and has fewer shells in it. The fossils are:—

Cardita nuculoides.
Ceromya papyracea, Sharpe.
Cucullaea jonesi.
Exogyra imbricata.
Gervillia dentata.
Modiola baini, Sharpe.
Ostrea.
Pholadomya dominicalis.
Pleuromya complicata.
Trigonia herzogi.
„ *conocardiiformis.*
„ *vau.*

In the sandy clays which form so large a part of these cliffs there are many thin shelly layers, crowded with small oysters, and less often with *Ptychomya complicata* and *Lima obliquissima.* These layers disappear within a few feet or yards.

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Lignite is abundant in both the clays and the harder beds; pieces eight inches long are not uncommon. In the big kloof on Ebb-en-vloed prospecting has been done on a thin layer of lignite, but it thins out within five feet of the outcrop on the kloof side. This lignite is in the clays and shales between 2 and 3 in Fig. 3, and if it were of any constancy it would crop out in the cliffs to the south-east.

The lignite appears to be in every way identical with that which occurs in the Wood beds. A sample from Eb-en-Vloed, analysed by Mr. J. G. Rose, Government Analyst, gave the following result:—

Moisture	10.41%	
Ash	14.80 „	
Volatile matter	42.40 „	(includes moisture and sulphur).
Fixed carbon	42.30 „	
Sulphur	5.90 „	

The sulphur is present in greater quantity than is usual in a substance of this nature, and the following analysis of the ash, also by Mr. Rose, shows that it probably exists, in combination with iron, as pyrites or marcasite:—

Silica and gangue	18.73%
Iron and aluminium oxides	64.06 „
Lime	3.43 „
Magnesia...	.34 „
Alkalis, chlorine, etc. (by difference)	13.44 „

The structure of the wood can be seen on broken surfaces of some pieces of the lignite.

On the farm Olifant's Kop there is a richly fossiliferous zone, rather higher than half-way down the steep slope to the river; the fossils occur in clayey limestone chiefly. The following species were collected there (P):—

A macrurous (cray-fish-like) crustacean.
Astarte herzogi.
Cardita nuculoides.
Ceromya papyracea.
Hamites africanus.
Modiola baini.
Pinna atherstonei.
Pleuromya baini.
Trigonia conocardiiformis.
„ „ (a related species).
„ *herzogi.*
„ *tatei.*
„ *vau.*
„ *ventricosa.*
Small gastropods.

These beds almost certainly lie upon the highest fossiliferous rocks of the Eb-en-Vloed cliffs. They dip at about 4° to the south.

The next outcrops down the river are on the left bank, 500 yards below Barkly Bridge, where there are yellow sandstones, with *Trigonia ventricosa*, Krauss.

From Barkly Bridge to Colchester the exposures are very poor, though they can be found on the bushy slopes on Fascadale, Ingleside, and Klein Vetmaak's Vlakte; on Fascadale outcrops of sandy limestone, with *Pleuromya baini*, *Astarte herzogi*, and *Ostrea*, appear at the surface about half-way down the slope, below the outcrops of the raised beach deposits.

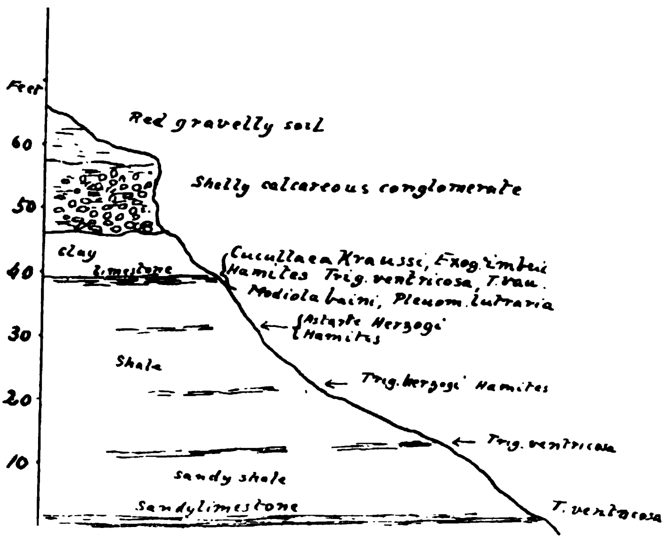

FIG. 4. Section in kloof behind Colchester.

On account of the absence of good exposures below Barkly Bridge it is difficult to ascertain the position of the fossiliferous rocks behind Colchester (a small village on Vetmaak's Vlakte, on left bank of Sunday's River), with reference to those elsewhere.

North-east of Mackay Bridge, by which the Grahamstown road crosses Sunday's River, there is an exposure of 70 feet of unfossiliferous clays, and these pass under the fossiliferous beds in the kloof behind Colchester. Somewhat over 50 feet of clays, with thin limestones interbedded with them, are to be seen

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here (Q). The section (Fig. 4) shows the distribution of the fossils, which include the following species:—

Hamites africanus.
Astarte herzogi.
Cucullaea kraussi.
Exogyra imbricata.
Modiola baini.
Pleuromya baini.
" *lutraria.*
Trigonia herzogi (large and small forms).
" *vau.*
" *ventricosa.*

This locality is near that called "McLaughlin's Bluff" by Stow,[1] but I could not identify the spot. The hill sides have doubtless altered in outward appearance since 1870, when the sketch on p. 500 of his paper was drawn, by the increase of low bush. The list of fossils from his locality given in Fig. 3 of his paper is not identical with the above, but there are several common to the two.

About half a mile nearer the mouth of the river there is a good exposure near the top of a side gully, near the end of the big kloof up the south-east side of which the road to Grahamstown is carried. At this place (R) the following fossils were found:—

Belemnites africanus, Tate.
Astarte herzogi.
Pholadomya dominicalis.
Trigonia vau.
" *ventricosa.*

The most remarkable feature here is the extraordinary abundance of *Trigonia ventricosa*, though other shells are not very numerous, and the collection is small in number of species. These beds are probably on a slightly horizon than the uppermost Uitenhage beds in the kloof behind Colchester.

There are many described species of mollusca and three cephalopods, known from the Uitenhage beds, which are not included in the above lists, for they were not found. There were several other mollusca and one cephalopod found, but not mentioned, because they have not yet been determined; they may be new species.

So far as the collections yet made give any evidence on the matter, it would appear that the beds exposed in the Coega and Sunday's River valleys cannot yet be subdivided into zones characterised by particular fossils.

[1] Stow, Q. J. G. S. Vol. XXVII. pp. 497-522.

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The highest beds exposed are probably those near locality (P) on Olifant's Kop, and a comparison of the fossils found there with those in the river section at Buck Kraal shows that there is little difference between them; the Olifant's Kop beds yielded more species of *Trigonia*, but the Cephalopod *Hamites africanus* is common to both.

It is to be noted, that at Wolve Kraal, a little further up the river, in beds that are probably on the same horizon as the Buck Kraal sections, both *Trigonia vau* and *T. concocardiiformis* occur in addition to *T. herzogi*.[1]

The Buck Kraal section is probably the lowest of those described here from Sunday's River above Barkly Bridge. The rocks in this valley were probably formed rapidly. The sandy muds and limestones contain a large amount of lignite, which was drift-wood carried down by the rivers, water-logged, and quickly buried under the accumulating sediments.

THE ZWARTKOPS SALT PAN.

In the neighbourhood of the salt pan there are no good exposures, though some shales and a band of limestone crop out on the north and north-western banks. In these beds *Trigonia vau* and a small form like *T. herzogi* occur (locality S on the plan). Stow[2] mentions the occurrence of echinoid spines, *Ostrea* and *Turritella*, as well as of *Trigonia*, at this place, and considers that the salt which is deposited in the pan comes from the salt contained in beds overlying those in which *Trigonia* occurs, but belonging to the same series, and representing material deposited in basins cut off from the open sea[3] In another place the present writer expressed the opinion that the salt must be derived from the strata overlying the Uitenhage series,[4] but having seen the salt incrustation on the sandstones exposed along the Uitenhage road near Addo Drift (p. 26), I believe Stow was right in tracing the origin of the salt to the Uitenhage beds. The fact that the salt beds above Addo drift must crop out on the Zoet Geneugd cliffs, though their outcrops there are not incrusted with salt, shows that the salt is local.

A borehole in the neighbourhood of the salt pan penetrated clays, sandstone, and blue shale to a depth of 94 feet.[5] There were no parts of the core available for examination, but it is probable that the "sandstone" of the record is really a calcareous rock like the sandy and clayey limestones of the Zwartkop's and Sunday's Rivers.

[1] Geol. Comm. 1900, p. 16.
[2] Stow, Q. J. G. S. Vol. XXVII. p. 505
[3] *Loc. cit.* p. 514.
[4] Introduction to Geology of Cape Colony, 1905, p. 386.
[5] Information kindly given me by Mr. Engleberg at the salt pan.

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Gypsum occurs in the form of crystalline plates about the size of a shilling in the sandy mud in the floor of the pan; it is evidently thrown down from solution.

The Volcanic Rocks.

The northern limit of the Uitenhage beds, as we have already seen, is a fault. Where these beds abut against the Witteberg formation, on Duncairn and to the east of that farm, the southernmost part of the quartzites is shattered. On the road from Sand Flats to Waggwa conglomerates of the Enon type, underlain by red sands, are seen dipping at an angle of about 20° to the southwards, and the Witteberg beds crop out a few yards to the north. There is a thickness of about 20 feet of breccia, made up of angular fragments of quartzite set in a sandy matrix, north of the Enon conglomerate; but the outcrops show a gradual passage from the breccia, which is evidently broken up quartzite with a matrix of the same rock finely comminuted, into the solid unbroken quartzite within a distance of some 30 yards. The nature of the fragments and matrix of the breccia make that rock easily distinguishable from the Enon conglomerate.

On Duncairn the volcanic rocks first appear, and they lie between the southernmost outcrops of the Witteberg quartzites and the Enon conglomerate. The quartzites here also are brecciated in the same way and to about the the same degree as on the Waggwa road. From Duncairn the volcanic rocks are known to extend westwards as far as a point behind Enon Missionary Station, a distance of 19 miles; how much further they appear at the surface is not known.

The manner in which the volcanic belt begins on the east is not clear, as the ground is covered with soil and thick vegetation, but it must swell rapidly to a width of about 600 yards. The rocks composing the belt here are amygdaloidal lava, more compact lava, and grey and pink tuffs. It was impossible to trace out the boundaries between the tuffs and the lava, but the lava contains many fragments of tuff, and in part, at least, behaves towards the tuff as an intrusive rock. The tuffs are fine-grained rocks, which look more like fine-grained argillaceous sandstones than volcanic tuffs; their constituents are too small to be determined with the aid of a lens only, but they are probably of the same nature as the similarly coloured tuffs from the same fissure further west.

The lavas are reddish rocks, with a compact dull matrix, in which felspar laths are often visible under a lens; other original constituents are probably present, as in the similar rocks to the westwards, to be described below; the lava contains many small irregularly shapel drusy cavities and rounded steam holes. These holes and the drusy cavities are sometimes lined with a thin

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layer of minute pale green crystals, which have not been determined; others are partly or wholly filled with chalcedony, or with chalcedony and quartz crystals; others again are filled with a zeolite, heulandite, and a few with calcite. A borehole has been put down in some red tuffs within half a mile of the east end of the belt, and down to a depth of 250 feet the rock seems to have been of more or less the same nature throughout, judging from the information given me by the owner of the farm.

About a mile west of the east end the volcanic belt widens out to over half a mile, and is divided into three zones by the presence of an elliptical area of breccia and tuff situated on the divide between kloofs running eastwards to Duncairn and those descending westwards to Thornleigh (part of Mimosa). The general relations of the rocks at this locality are shown in Fig. 5,

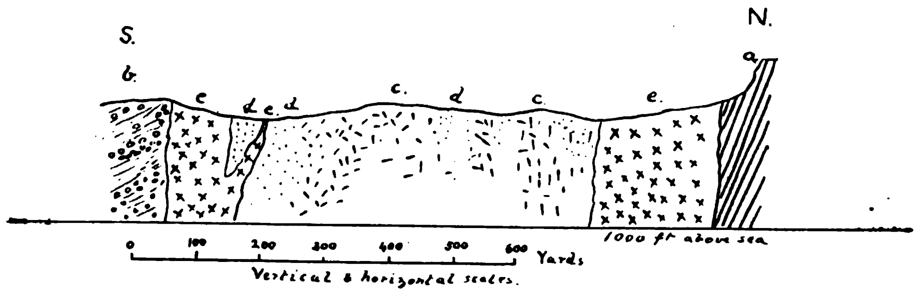

FIG. 5.—Section drawn north and south through the volcanic belt on the divide between Mimosa and Duncairn. *a*, Witteberg quartzites. *b*, Enon beds. *c*, *d*, *e*, breccias, tuffs, and lava of volcanic belt.

which is a section drawn from north to south through the belt of volcanic rocks.

The lava is a dull red rock (a basalt), with small drusy cavities and larger steam holes, though in places it becomes more compact by the decrease in the number of these spaces. Under the microscope the base [1357-1359] is opaque, owing to the amount of rusty iron oxide present, but very minute crystallites, perhaps of felspar, are scattered through it. In this matrix there are abundant grains of augite, which very rarely have one or more straight boundaries, and various sized crystals of a basic plagioclase, some of which is labradorite. Some of the plagioclase crystals have different properties in different parts; the change is very gradual and regular from within outwards. Olivine is absent from the two sections cut. The steam holes and drusy cavities are filled with a zeolite, chalcedony, chlorite, and a nearly isotropic mineral, which is probably analcite. The felspars are considerably altered, and the augite is frequently stained red, like the opaque base, but to a smaller extent. The larger felspars are often packed together, and appear to be

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rather large porphyritic crystals before the various individuals in the lump are distinguished; there is no sharp distinction between these larger individuals which may be thus grown together and the smaller individuals, for there are many crystals of intermediate sizes.

On the south side of the mass of tuffs and breccias the basalt forms small dykes in the fragmental rocks, which are distinctly hardened near the contact, and have both irregularly shaped and rounded cavities, partially or entirely filled with chalcedony and quartz. A section [1358] from a junction of the lava and tuff shows that the latter rock is made up of small angular fragments of quartz, felspar, a few pieces of augite and dark mica, and small bits of opaque red rock, which is evidently derived from the ground mass of the lava[1]; these fragments are in a ground mass which is partly chalcedony and partly dusty matter, whose nature is uncertain. The lava in this slice is not different from the basalt obtained at a distance from the tuff; it shows no signs of chilling, such as a greater amount of amorphous base or a more pronounced porphyritic structure.

On the path which leads through the bush in the kloof on the north-east corner of Thornleigh (Mimosa) there is a coarse breccia, containing subangular pieces of reddish chalcedony or chert as much as an inch in diameter. This breccia was seen, in small outcrops and loose fragments only, between lava on the south and the Dwyka series on the north. It undoubtedly belongs to the volcanic group; there are the more usual fine-grained tuffs in the immediate vicinity, and a coarse breccia with very similar characters occurs along with the tuffs in the neck to the east, though chert fragments were not noticed in the latter rock.

The basalt form a wide strip, passing south of the tuffs described above, and makes a ridge sloping westwards to the main kloof on Mimosa. At the place where two kloofs join to form the main valley there is a small area of buff-coloured and pink tuffs, the lava lies to the south and the Dwyka boulder beds to the north. This seems to be a small neck, like the breecia and tuff neck already described and the one on the Nieuw Post road, to be mentioned below.

There is a rather large lava outcrop in a garden situated in the Mimosa valley at the end of the lava ridge, and there are bands of more and less amygdaloidal rock running across the outcrops dipping about 20° to S. 10° W. There are also irregular layers of pipe-amygdaloid at this spot. The

[1] In a description of the "Volcanic Fissure under Zuurberg" in Trans. S. A. Phil. Soc., Vol. XVI. Part 2, p. 193 it is stated that "pieces of lava do not occur in the fragmental rocks" of the group. This is a misstatement based on inspection of specimens alone. Thin sections of the red and pink tuffs show innumerable minute bits of lava; the light coloured tuffs are nearly free from them, though some lava fragments are seen in these also.

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pipes are perpendicular to the layers. The bands of various textures are not definitely separated from each other, but are parts of one rock mass. Fragments of pipe-amygdaloid were seen again near the boundary between Duncairn and Mimosa, but not in place.

The old road from Mimosa to Nieuw Post ascends the escarpment by means of the divide between the streams which run into the main valley on Mimosa and those which join the Coerney River. Immediately south of the Witteberg outcrops there is a tract of ground in which the underlying rock is concealed, but a considerable variety of fragmental rocks, belonging to the volcanic group, crop out southwards of this doubtful area. It is possible that a part of the Dwyka series, which is first met with west of the neck on the Duncairn-Mimosa boundary, occurs here also, but this is not likely, and it is very improbable that any part of the Dwyka boulder beds is present at this spot. A section through the volcanic belt is given in Fig. 6, which shows

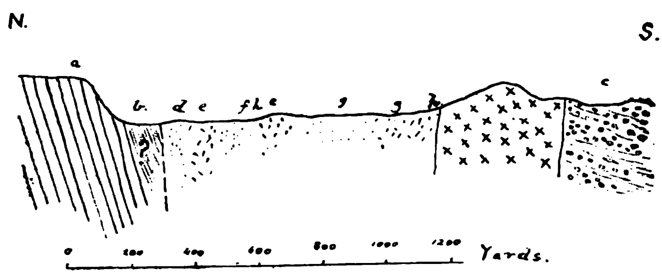

FIG. 6.—Section through the volcanic belt on Mimosa. *a*, Witteberg beds of the Nieuw Post escarpment. *b*, Lower Dwyka shales possibly present. *c*, Enon beds. *d*, brown sandy micaceous tuff. *e*, breccia. *f*, green tuff. *g*, red and light coloured tuffs. *h*, pink tuffs.

the succession of varieties of rock in the belt along a certain line. The main point is the occurrence of a large mass of breccia and tuffs of various kinds in a locality where the band of volcanic rocks swells out to more than its usual width. A thick band of lava separates the fragmental rocks of this neck-like expansion and the conglomerates and sands of the Uitenhage beds to the south.

The rocks at this place are not well exposed, but several specimens were taken from outcrops that barely rise above the ground on the cattle-track itself; off the track outcrops are still less frequently seen in the bush, which is quite luxuriant on the steep hill sides south of the Zuurberg.

The brown micaceous rock, which is the northernmost exposed member of the volcanic group, looks not unlike a rather soft sandstone. It has circular green spots on its surface, evidently sections through spherical patches of a green tuff like

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that described below. Under the microscope a section of this brown rock [1348] shows more or less angular and uniformly sized grains of quartz and plagioclase felspar closely packed together, a few flakes of mica and grains of zircon. The matter between the grains is indeterminable, but it is chiefly made of very minute brightly polarizing flakes.

There are many outcrops of a breccia with a pale yellowish brown matrix, containing a few pieces of quartzite and kaolinised felspar, and very many more or less rounded lumps of a brownish substance, which in the hand specimens seems to differ in colour only from the paler matrix. In thin section [1349] small fragments of a granitic rock, consisting of quartz and felspar, are seen, in addition to the quartzite and altered felspar. The matrix is composed of chips of quartz, microcline, plagioclase, and zircon set in a base of very minute fragments; the base as a whole is isotropic. There are rounded areas, in which the proportion of base to quartz and other chips is greater than elsewhere, and in which the base is yellower in colour by transmitted light. These areas are the darker patches in the hand specimens, and they are evidently pellets embedded in a matrix of very similar nature.

Another section [1350] taken from a different outcrop of this type of breccia shows grains of garnet and green hornblende in addition to the minerals mentioned above. There is also some chalcedonic silica in this rock, playing the part of matrix in certain portions of the slide.

In the green breccias thin sections [1351, 1352] show that the colour is given by the abundance of weakly, doubly refracting flakes of a chloritic mineral in the matrix. In other respects there is no appreciable difference between the green rocks and the brownish or yellow tuffs.

A section through one of the red tuffs [1353] reveals a great difference between these and the other fragmental rocks; the chips of quartz and felspar are accompanied by innumerable small particles. of deep brown or reddish glassy matter, with angular or rounded boundaries. These are evidently pieces of lava, and they contain small steam holes or amygdales, small felspar laths, and pseudomorphs, often small crysals of olivine and augite. The felspar laths have low extinction angles, and appear to belong to a more acid variety of plagioclase than one expects to meet with in olivine basalts.

The lava on the south side of the fragmental rock is a close-grained red rock, with many steam holes, filled with calcite, analcite, heulandite, chalcedony, and other minerals. A section from the rock exposed on the ridge south of the tuffs [1355] has a ground mass which is almost opaque, and is composed of microlites that are scarcely translucent, owing to the amount of dusty matter in them. These microlites are surrounded by opaque red particles, hydrated oxide of iron. Plagioclase

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crystals lie in the ground mass, but they are usually altered to a considerable extent; the extinction angles about the planes of twinning point to their being oligoclase. Small, but quite fresh augite crystals and serpentinised olivines are the other porphyritic constituents.

West of the neck-like expansion of the volcanic belt on the Nieuw Post road the lava forms a band over 1,000 yards wide, out of which a valley and a ridge trending westwards towards Coerney River have been cut..

Where the Coerney River traverses the belt the width of the latter has decreased very greatly, and the only rock belonging to it exposed near the river is a coarse quartzite breccia, with much calcite in the matrix. This breccia appears in the river bed over a distance of about 100 feet, and these outcrops are rather far from the nearest outcrop of the Enon beds down stream, while 30 yards of concealed rock separate them from the southernmost Dwyka exposures up stream. The lava in the valley and ridge to the east of the river varies considerably in texture from place to place, according to the abundance and size of the steam holes, and there are patches of red and yellowish tuffs associated with it, but it retains the same general characters as it has further east.

West of the Coerney River there is only a narrow strip of lava present, and it was not followed continuously along the three miles of bush country to the valley on Rockwood, where it is exposed on the road to Zuurberg. At this locality the relationship of the lava to the sedimentary rocks north and south of the fault is most clearly seen, though at the time of my visit the actual junctions were not exposed. It is very probable, however, that the contacts may be seen after unusually heavy rains or when a particular section of the road is being repaired.

The road from the mountain goes down the right-hand side of the valley in such a way as to traverse the Upper Dwyka shales, the volcanic belt, and finally the Enon beds. The Upper Dwyka shales are highly disturbed, twisted, and traversed by small faults where they are seen in the roadside quarry and ditch nearest to the volcanic rock. The volcanic rock is at this place a highly amygdaloidal lava, red in colour, with a rather peculiar appearance, owing to the abundance of heulandite and its pearly lustre on the basal cleavage faces. The rock itself is a basalt like that at Duncairn and Mimosa. Near the bed of the stream, where it crosses the volcanic belt, a well has been sunk on the lava. The rock from the top of the well is just like that seen by the roadside, but from lower down a dark-coloured, heavy rock, with steam holes filled with a black soft substance, has been taken out; under the microscope the latter is seen to be a serpentinous mineral. The difference in colour between this rock and the similar basalt of the outcrops seems to be due to the production of red hydrous oxides of iron in the ground mass of the rock at the surface.

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The nearest outcrop of Enon beds is about 100 yards down the road from the lava, though owing to the low angle at which the road crosses the boundary between the two rocks, the Enon beds exposed in the small road-metal pit must be within 20 feet or so of the lava. The Enon beds here consist of red conglomerates, and the dip is southwards at 35°. Further down the road towards Coerney Station the dip of the variously coloured marls decreases considerably.[1]

From the Zuurberg Pass road the volcanic rocks were followed up the ridge to the northern part of Kremlin, across Slagboom to the White River, and behind the conglomerate hills on Enon Mission Station. Throughout this range of nine miles tuffs appear to take a small part in filling the fissure, but there are several outcrops of tuffs and breccia on Kremlin and Slagboom. Generally, the exposures are too few to allow the relation of the lava to the tuffs to be ascertained, but on the cattle track from Slagboom to the Zuurberg road the lava is seen to penetrate the tuffs in the form of veins or small dykes.[2]

The width of the volcanic belt where the Zuurberg road crosses it is about 100 yards, but it swells out to 300 on Kremlin, and 800 on Slagboom. On the latter farm the course of the fissure turns towards the north-west, where it is crossed by the White River, and then turns back again to nearly due west. The trend of the Dwyka series does not take a correspondingly large turn, and the upper shales are not met with far west of the boundary between Kremlin and Rockwood Estate. On Slagboom the volcanic rocks are seen to be in contact with the Dwyka boulder beds on the north.

Where the White River has cut through the volcanic rocks the latter are seen to occupy a vertical or nearly vertical fissure. The height of the top of the volcanic ridge on Slagboom is about 800 feet above the river, and on looking westwards across the valley one can see the volcanic rocks, with the Uitenhage beds to the south and the older rocks to the north, very clearly. On the Zuurberg Pass road the same relation can be made out, but not so obviously as in the valley of the White River, because the section is less extensive.

The Nature and Origin of the Volcanic Belt.

The fact that a fault exists along the northern boundary of the Uitenhage formation in this area has already been pointed out. It is obvious from the foregoing description and from the map that the volcanic rocks coincide in position with the fault;

[1] A section through this part of the belt is given in Fig. 1. on p. 192 of Trans. S. A. Philos. Soc., Vol. XVI., 1905.

[2] A plan of these outcrops is given in Fig. 2, p. 192 of the paper cited above.

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they lie between the Uitenhage beds on the downthrow side of the fault and the Dwyka and Witteberg formations on the upthrow side.

The absence of the Dwyka series on Duncairn and east of that place, the cutting out of the boulder beds and probably also of the Lower shales on Mimosa, the elliptical outcrop of the Upper shales near the Zuurberg road and its disappearance on Kremlin prove that the volcanic rocks do not follow the Dwyka series conformably.

It might be held that the volcanic group came into existence after the Dwyka and older rocks had suffered extensive denudation, but before the Uitenhage beds were deposited. There are great difficulties in the way of accepting this view; for no fragments of lava or tuffs have been recorded from the Uitenhage beds, although the lava is a very conspicuous rock, and the conglomerates have been examined with the object of finding lava pebbles at all the available exposures between Enon and Bushman's River; the Coega valley conglomerates have also been carefully looked at, though before the existence of the volcanic rocks was known. The lavas and tuffs have evidently never been subjected to the movements and pressure that brought about the incipient cleavage and the folding of the rocks in the Zuurberg.

There is no evidence of the intercalation of the lava with the lowest of the Uitenhage beds, nor have volcanic rocks ever been found interbedded with this formation elsewhere in the Colony.

There seems to be no other explanation than that adopted when the belt was being examined, that the volcanic rocks rose along the line of faulting during or after the production of the fault. This explanation does not account for certain facts, the presence of a band of pipe-amygdaloid in the Mimosa valley, where the "pipes" are arranged perpendicularly to a plane which dips about 20° towards S. 10° W., and the existence of a band of scoriaceous lava parallel to the pipe rock.

The lava does not resemble closely any previously described Colonial rocks, but it is more like some of the Drakensberg lavas than any other volcanic rock in the Colony.

In Willowmore[1] there is a broad band of shattered rock, quartzite of the Table Mountain series, on the north side of the faulted outlier of Enon conglomerate of Baviaan's Kloof. This shattered belt is three-quarters of a mile wide. Broken rocks are often found in connection with normal faults, but brecciation on this scale is not to be accounted for in the same way as the more limited masses of breccia along ordinary faults.

* Schwarz "Ann. Rep. Geol. Comm. for 1903, pp. 132-3.

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It is permissible to look upon these bands of broken rocks as having been produced by explosions of the kind that gave rise to the remarkable breccias of Swabia, elaborately described and discussed by Professor W. Branco.[1] There is one important difference between the two regions. Professor Branco shows that the Swabian explosions took place quite independently of structural features, such as faults, and that they are closely resembled by the Kimberley pipes of South Africa, but in the Zuurberg region the explosions took advantage of an existing line of weakness or faulting.

Whether the explosions took place during or after the movement along the fault is a difficult question to settle.

In connection with this belt of volcanic rocks it is interesting to notice that its occurrence may have been partly responsible for the old view that the Dwyka boulder beds were of volcanic origin. A. G. Bain, Atherstone, and Pinchin knew this district, and their visits to the foot hills of Zuurberg are remembered by at least one of the old residents, Mr. Walton, of Mimosa. The volcanic rock, as is evident from the map attached to this Report, replaces the Dwyka to a certain extent, *i.e.*, it occurs on the same line of strike. Atherstone, in his well-known paper, entitled "Geology of Uitenhage," in the "Eastern Province Monthly Magazine," 1857, says that at this locality the "claystone porphyry" is vesicular, evidently in reference to the amygdaloidal and vesicular basalt of the Zuurberg fissure.

The Warm Springs at Balmoral.

The water issues from several spots on a hill south of the Coega River on Balmoral at a temperature slightly higher than that of the air on a warm summer's day, so far as I know the temperature has not been accurately taken. The water has a distinct taste of iron, and the large amount of iron oxides deposited by it show that an iron compound, probably ferrous carbonate, is one of the chief constituents in solution.

From one of the springs water issues which has an astringent taste, like that of alum.

The deposit of black and brown earthy oxides of iron conceals the underlying rock, but there are cuttings through gravelly material that may perhaps belong to the Uitenhage series, and a large jointed slab of quartzite, through which one of the springs issues, might belong to the Table Mountain series.

[1] To Prof. Branco I am indebted for copies of his works on this subject, viz., "Schwabens 125 Vulkan-Embryonen." Stuttgart, 1894. "Die Gries-Breccien des Vorrieses als von Spalten unabhängige, früheste Stadien embryonaler Vulcanbildung" and "Zur Spaltungfrage der Vulcane." Sitzungsberichte der Königl. Preuss. Akad. der Wiss. XXXVI., 1903., p. 748 and p. 757. "Das Kryptovulcanische Becken von Steinheim," Abh. d. Königl. Preuss. Akad. d. Wiss. 1905.

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At one spot a shaft was sunk 40 feet into the ferruginous deposit in the hope of finding coal. The bottom of the deposit was not reached.

At the spring which issues from the joints in the quartzite slab a yellow mineral with metallic lustre occurs in the sand through which water bubbles, and the same mineral is found cementing together the sand in places at the bottom and sides of the cutting near the eye of the spring. The mineral has a pale yellow colour, and is occasionally in the form of irregular four-sided pyramids, though generally no particular shape can be seen. On exposure to the air it becomes dull, in the manner of marcasite.

Mr. J. G. Rose, of the Government Analytical Laboratory, separated the yellow mineral from the sand and analysed it, with the following results:—

Iron	36·4
Sulphur	32·4
Sulphuric oxide...	8·2
Silica and gangen	8·5
Moisture	7·1
Alkalis as Na_2O	3·6
Organic matter (by difference)...	3·8
	100·0

Mr. Rose says: "' Arsenic and antimony are present only in very faint traces (less than .001%), as are lime, magnesium, and chlorine. The chief constituent appears to be iron pyrites ($Fe\ S_2$), which forms about two-thirds of the weight of the substance. Some of the iron (3-4%) is in the ferrous state, apparently as ferrous sulphate ($Fe\ SO_4$), and some as ferric oxide, while the alkalies are probably in combination as sulphates."

Marine Beds of Tertiary or Recent Age.

In the Addo Hills, Grass Ridge, and the flat ground between Zwartkops and Coega Rivers, there are conglomerates and shelly limestones lying unconformably on the Uitenhage series.

On A. G. Bain's map,[1] published in 1856, these rocks are indicated and called "Tertiary," but no distinct evidence has ever been obtained to prove that they contain fossils of extinct species. Their occurrence at various elevations from a few feet (on the shores of Algoa Bay) up to some 1,300 feet (Addo Heights) make it probable that they include deposits representing a very considerable period.

[1] Trans. Geol. Soc. Lond., Vol. VII., 1856.

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The lowest lying of the marine beds examined during the present survey are those on the left side of Sunday's River, near Mackay Bridge. They lie about 80 feet above the sea, and they make a conspicuous feature in the hillside, because they are much harder than the underlying Uitenhage beds. At this place there are about 30 feet of these beds exposed. The greater part of the beds is made of a hard shelly limestone, from which the shells themselves have mostly been removed by solution. It is very difficult to obtain good specimens of these shells for determination. Pebbles are frequently abundant in these rocks, and parts of them are evidently beach deposits.

Shelly limestones like those along Sunday's River occur at many places on the Addo Hills, where wells have been sunk through them, and they are quarried for building stone near Sand Flats. Parts of the limestone south of Sand Flats, and on the hills near De Bruyn's Kraal, to the east, are very hard rocks, made up of broken shells, sand grains, and a few whole shells, but no collection could be made from them, because the shells would not break out, and there was no time to spend in chipping them out of the solid rock.

Though no definite evidence of the Tertiary age of any of these high-level limestones is yet known, it is by no means unlikely that such evidence will be forthcoming.

The Gravels.

Along the Sunday's and Coega Rivers there are frequently to be found patches of gravel at various heights above the alluvial flats near the present beds. These gravels are at once distinguished from the beach deposits by having their pebbles more closely packed, by the presence of various land and fresh water snails in place of the marine shells, which are represented by a few rolled fragments, and by the absence of a calcareous cement. Most of the pebbles were certainly got from the beach deposits upon which the higher gravels encroach.

APPENDIX.

Occurrence of the Wood Beds on Loerie and Gamtoos Rivers.

During the past year prospecting work has been done on the lignite in the Wood beds in the south-western corner of Uitenhage. Three drives have been made, two on the right bank of the Loerie River, about two and four miles respectively above its confluence with the Gamtoos, and the third is on the left bank of Gamtoos River, about three-quarters of a mile above the Humansdorp-road bridge.

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The upper drive on Loerie River has exposed sandstones, sandy clays, and conglomerates dipping 20° to N. 20° E. They are irregularly-bedded rocks, and thin layers of pebbles are found in the clays. A thick bed of conglomerate at the top of the drive, and exposed in the bank above it, is about three feet thick, and has an irregular floor; hollows in the underlying clay are filled with yellow, sandy conglomerate. The pebbles are of quartzite chiefly, but quartz schist, vein quartz, and slate are also found in the conglomerates.

The sandstones and clays have irregularly-shaped lumps of pyrites in them, evidently formed in the positions they now occupy. Lignite occurs in thin lenticular layers; the thickest exposed at the time of my visit measured two inches, and tapered out to nothing in a distance of eighteen inches. Thicker layers have, however, been found, but they also thin out rapidly. In many pieces of lignite the original structure of the wood can be seen as faint, originally concentric rings, now flattened out into ellipses. Some lignite occurs in fibrous streaks, branching in various directions through the clays; these are evidently roots, but no stems were found in connection with them.

In addition to the lignite, a brown or yellow semi-transparent inflammable resinous substance occurs in these beds. It is found in three forms: (1) Mixed with the lignite in lenticles; (2) as independent lenticles up to quarter of an inch in thickness; and (3) as small pebble-like lumps, apparently water-worn.

An analysis of this resinous mineral, by Mr. J. G. Rose, of the Government Analytical Laboratory, gave:—

Organic and volatile matter	50.97%.
Ash	49.03%.

The ash consists of silica, oxides of iron, and alumina and a small amount of alkalies; it was probably sandy matter mixed up with the resin.

This semi-transparent stuff is certainly a fossil resin, and the occurrence of such substances does not seem to have been recorded previously from any rocks in Cape Colony. It occurs also in the core from a bore-hole put down in the Uitenhage beds by the Railway Department at Glenconnor.

The lower drive on Loerie River is in very similar beds to those described above, and similar lignite is got from them.

The opening on the Gamtoos River bank is at the foot of a slope on which lenticular layers of conglomerate and sandy clays crop out. Grey clays and shales are exposed in the drive, and

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these contain more or less imperfect remains of plants. The recognisable plants are :—

Sphenopteris fittoni (Seward).
Onychiopsis mantelli (Brongn).
Zamites recta? (Tate).
Taxites?

The three first-named plants occur also in the Wood beds near Dunbrody, on Sunday's River, and *Taxites* is found at Herbertsdale. Lignite similar to that found on the Loerie River is interbedded with the clays and shales at the Gamtoos drive.

The lignite from this neighbourhood is so like that from the Sunday's River valley, of which an analysis is given on another page, that there was no need to have another analysis made, especially as there is no probability of its ever having an economic value.

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GEOLOGICAL SURVEY

OF THE

COASTAL PLATEAU IN THE DIVISIONS OF GEORGE, KNYSNA, UNIONDALE, AND HUMANSDORP.

BY

ERNEST H. L. SCHWARZ.

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GEOLOGICAL SURVEY OF THE COASTAL PLATEAU
IN THE DIVISIONS OF
GEORGE, KNYSNA, UNIONDALE, AND HUMANSDORP.

E. H. L. SCHWARZ.

INTRODUCTION.

The present report deals with the coast belt lying to the south of the Outeniqua and Long Kloof Mountains. In 1898 Messrs. Rogers and Schwarz published an account of the district to the west of George. In 1899 the writer described the Knysna Division, in so far as it was traversed in looking for outcrops of Enon conglomerate containing fossils, the nature of which rock being at that time not properly understood.[2] In 1903 the writer described the Uniondale Division,[3] and last year the Long Kloof,[4] to the north of the district now under discussion.

The area consists of a background of mountains, rising to a maximum of 5,497 feet,[5] and a comparatively narrow ledge forming a coastal plateau, shelving slightly towards the sea and elevated some 700 feet above sea-level. The plateau is cut off on the south very abruptly, with precipitous cliffs that can only be scaled at a few points, and there is scarcely any beach at the base. The rivers have cut deep gorges in this plateau, and for the most part are useless for irrigation purposes, from their depth below the general surface; where, however, the rocks traversed by the streams are soft, either consisting of Bokkeveld slates or Enon conglomerate, there are wider valleys and fertile tracts of alluvium. At one part an immense bank of sand-dunes has been added to the land in front of the cliffs, and between there is a low-lying tract of country, containing the famous George and Knsyna Lakes.

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[1] Report on the Southern Districts between the Breede River and George. Ann. Rept. Geol. Comm. 1898, Cape Town, 1900, pp. 37-54.

[2] Knysna, between the Gouwkamma and the Blue Krantz Rivers, Ann. Rept. 1899, Cape Town, 1900, pp. 51-64.

[3] Geological Survey of Prince Albert, Willowmore and Uniondale, Ann. Rept. 1903, Cape Town, 1904, pp. 72-137.

[4] Geological Survey of the Long Kloof, Ann. Rept. 1904, Cape Town 1905, pp. 47-69.

[5] Sir David Gill, Geodetic Survey of S. Africa, Vol. II., Cape Town, 1901, p. 181.

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Among the rock formations, we have the end of the George boss of granite, and another mass, in outcrop showing as a boss, but probably only an immense horizontal offshoot from the great triangular basement of granite that underlies the extreme south-western portion of the Colony. Round the granite outcrops there are slates, phyllites, quartzites, carbonaceous shales, and peculiar white rocks, containing felspar and garnets; these are pre-Cape rocks, formerly called Malmesbury beds, but since the 1898 Report was written, so much new light has been thrown on these old sedimentary rocks that we now hesitate to correlate any isolated outcrop with the type occurrence in the neighbourhood of the Cape Peninsula; these old rocks are injected with granite veins and dykes of basic composition, now reduced to the condition of hornblende schists.

Stratigraphically, above these last, comes the Table Mountain sandstone, forming the whole of the mountains and by far the larger part of the plateau, especially to the east.

The Bokkeveld series exists by favour of the great folds that have let down small portions of these beds in among the harder rocks of the Table Mountain series, and the enormous denudation that has swept vast quantities of material into the sea, has left these sunken portions as small inliers among the older series.

A more recent folding has let down a softer formation in among both the Table Mountain and Bokkeveld series; this is the Uitenhage series, which is here represented by banks of conglomerate, sand, and clay, which were formerly called Enon conglomerate; now, however, when we know that the true Enon conglomerate forms a basement to a large thickness of beds, the top of which only contains marine fossils, and we find the same marine fossils in the conglomerate in Knysna, we are not strictly correct in calling the Knysna rock "Enon conglomerate," though the great similarity in texture and composition would render the use of the term very convenient.

The sand is massed up in great dunes, reaching a maximum height of 912 feet at Belvidere, but ordinarily not more than 500 feet high; whether the Belvidere hills stand upon a basement of older rocks, themselves elevated above sea-level, as is most probable, or whether the sand commences right away from sea-level, cannot be accurately made out, owing to the whole country being covered, but we notice that the base of the dunes west of Knysna rest directly upon the coastal plateau, and that eastwards of the port the level becomes lower and lower, and west of the boundary, between the George and Knysna Divisions, the sand which has been consolidated into limestone, passes beneath the waters of the ocean.

In the larger estuaries of the rivers, such as those of the Knsyna and Bitou Rivers, there is a deep accumulation of greenish sand, and sand containing sub-fossil shells of species

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that are not common now on the shores of the Colony, though they are found in abundance on the Natal coast. This estuarine deposit is many scores of feet deep, and points to a period when the land was very much higher than it is at present, for otherwise we cannot account for the valleys having been so deeply eroded.

The soil throughout the district, except on the alluvial flats and on the narrow strips of Bokkeveld beds, is sour, that is, has an acid reaction, due to the accumulation of organic acids elaborated by the roots of the plants. Under the soil there is a sub-soil composed of rock fragments, coated with iron oxide, or simply granular masses of sand cemented with iron oxide; this forms hard banks of ironstone when exposed on the surface, and is only found under sour soil. The acidity of the soil is found equally on granite and Table Mountain sandstone, and is due to want of drainage, rather than to the nature of the rock sub-stratum.

THE GRANITE AND PRE-CAPE ROCKS.

The granite mass of George is in many ways different from the granite found to the west, in Robertson, Paarl, Malmesbury, and adjoining districts, for it is principally a white mica granite, whereas the western rock is usually a biotite granite. Exceptions to this rule naturally occur, but, on the whole, the general statement is correct. In another way, the granite of George is different from the western rock, in regard to its internal nature; usually such granite masses are solid bosses, that have segregation veins within their substance and dykes coming off from the parent mass, but otherwise the cores are in the state in which they first consolidated, and show no evidence of having been affected by the enormous stresses that acted around them, and altered and crumpled the rocks which they have injected. At Robertson there is a great boss of unaltered granite, surrounded by a zone of gneiss, schist, and rock derived partly from granite veins and partly from the sedimentary series, the last showing how intense the crushing force must have been which could thus form a transfusion rock. The course of the great Worcester-Swellendam fault, at the base of the Langebergen, clearly enough demonstrates the same thing, for this fault, which comes from near Worcester, is deflected in a half-circle round the granite boss, and resumes its straight course on the other side; or, to put it another way, the mountain building forces, which caused the whole strip of country to the south of the fault to drop some 10,000 feet, has been insufficient to affect the granite. In the George granite, however, the mass of the rock has been shifted and crushed, while later injections have been thrust into the gaping crevices which formed during the action of the mountain building forces.

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Some fine examples of later injections are exhibited in the cuttings along the new George-Mossel Bay railway, those near the Malgaten River especially; here we have the rock riddled with large and small veins of granite, profusely scattered with tourmaline crystals. In a road-metal quarry some three and a half miles from George, towards Knsyna, there is shown a very large dyke of binary granite, with a mere trace of biotite and tourmaline, injecting a mass of gneiss, which here has weathered into a loose sand. Coming from the dyke, there are quartz veins, which show faulting. Still further along the road, before descending the hill to the Kat River, there is a big granite dyke, itself riddled with smaller dykes of fine-grained rock, and binary granite with tourmaline. The first kind of dyke cuts through the coarser rock in the usual way, but the tourmaline pegmatite follows joint planes in the rock, and is undoubtedly subsequent to the crushing which the parent rock underwent.

Down towards the Kat River, however, we enter a region of slates, heavily injected with granite dykes, which were not mapped in detail; all we can say is, that the main mass of the George granite has come to an end. The true relations of the igneous and sedimentary rocks about here must always remain indefinite; the country has been denuded and levelled to a plain some 700 feet above sea-level, and this has been cut into by a number of rivers, which have made winding gorges, with precipitous sides. It is only in these gorges that one obtains outcrops of rocks, all the surface of the high-level plain being covered with soil, and the sections exhibited in the gorges are so varying that any attempt to piece together the geology of the country from them ends in hopeless confusion.

On the north and east the granite of George is bounded by slates, normal, sheared, clay slates, with occasional rich development of mica; they are badly exposed, and the various kinds that one sees around Worcester, for instance, all merge here into a brown micaceous product resulting from weathering. To the east of the George granite there is a change, for there is a great development of andalusite, sometimes in perfectly formed crystals, at others in half-formed crystals, that are mere knots and lumps in the micaceous rock.

At one place on the way to Knysna, after passing the first bridge, namely, that over the Kat River, and about five miles from George Town, there is a very interesting outcrop of andalusite schist, which has often been referred to in descriptions of South African geology. In the sheared clay-slates there is a small dyke of muscovite granite, showing in the road-cutting an elliptical section; on the lower side there is a number of very small accessory dykes, not more than an inch or so in diameter. The major axis of the elipse and the direction of the dip of the clay-slates is about south-east, 45°. On the upper side there is a zone of clay-slates, sheared, and presenting no particular

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features of interest, but then suddenly, some five yards from the granite dyke, there is a magnificent section of andalusite schist, with big crystals, up to two inches in length, scattered all over the surface. There seems to be no alteration in the composition of the slate to account for the change, and one is led to conclude that the new mineral formation does not take place in the zone of greatest heating.

On the south, the George granite is intensely jointed, with a general dip of the joint planes to the south or a little to the east of south. A north and south jointing super-added, cuts the mass into immense blocks, which weather out in the stream beds. The lower course of the Malgaten River shows this very well, especially where the new railway bridge will be built. On the extreme south, the rock becomes a gneiss, and is cut off by very steep cliffs, which fall towards the sea, with an inclination of 60° and more.

Near the Gwaayang's River, along the railway-cutting, there is a thin strip of slate in the substance of the granite; it is only a few feet thick, and is in the condition of phyllite. Further towards the coast, there is a wider band, and right on the coast, at Herold's Bay, there is exposed a narrow fringe of slate, the gneiss having been worn from off it.

As we go eastwards, this extraordinary relation of the gneiss, slate, and granite becomes clearer The first thin bed of slate widens out into the general mass of slate east of the great granite boss, but the second contains many peculiar characteristics; and though it eventually merges into the general mass of slate, it is separated from it for a good distance by a zone thickly penetrated by granite veins.

On the seaward side, the granite turns into a gneiss, and overlies the slate, dipping seaward at from 45° to 60°. It continues eastwards as a narrow belt, forming the prominent headlands on the coast as far as the Kaaiman's River; thence it skirts the edge of the high-level plateau, which is from this point situated inland, owing to the accumulation of sand dunes in front of it. The strike of this belt, also, alters at this point, from N.E. to E.N.E., and there is a very great importance attached to this change in direction, which will be discussed later. Further east, it joins up with the Touw's River-Hooge Kraal mass of granite. I take this mass of gneiss to be a once vertical dyke of granite that joined the two large bosses, and that subsequently earth movements were started, which altered the rock into a gneiss, and caused it to assume an inclined position.

The gneiss grades off on the under side, that is, on the north, into peculiar felspathic white rocks, containing zoisite and colourless hornblende, as well as garnet, all three alteration products of the original granite. This zone of intense dynamo-metamorphism apparently occurred only on the north side of the dyke. There is very constantly on the under-side a dyke of

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what was probably once dolerite, but which now exists in the form of hornblende schist. After this come quartzitic rocks and then ordinary phyllites, intensely sheared and crumpled.

This succession can be followed very well at Victoria Bay and along the fine sections between Kaaiman's Gat and the Wilderness. The phyllites continue backwards from the gneiss for some distance, all dipping at an angle of 60° to the south-east or east-south-east, sometimes with incipient alteration showing as spots and knots on the rocks. Then come quartzites and carbonaceous slates. The latter contain a notable percentage of plumbago in a flocculent form. One sees these black slates at many points in the pre-Cape rocks, especially near limestones—for instance, in Dassies Hoek in Robertson and in the Cango District in Oudtshoorn. In George they are well exposed on the road going down to Victoria Bay, at the Schaapkop's River mouth, at Kaaiman's River, and on the road down to the Wilderness; they are also found north of the Hooge Kraal granite. I do not think that any commercial value attaches to the rock, owing to the small content of carbon, and the flocculent form in which it occurs, which would render concentration impossible.

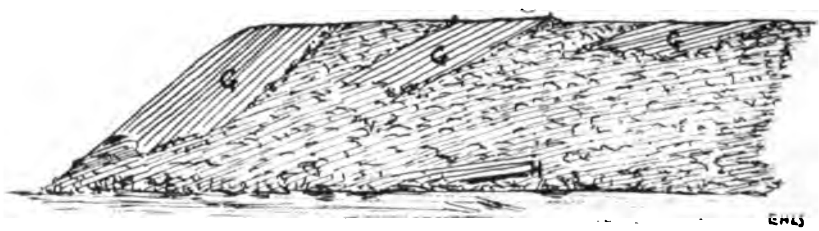

FIG. 1.—The mouth of the Touw's River, showing the beds of gneiss, G, repeated three times by faulting. At the water's edge there are white felspathic rocks, with hornblende schist, H.

At Schaapkop's River an excellent section is exposed in the river bed; the black rock is seen tonguing into white quartzites, and many granite veins traverse the whole series; lenticles of the black rock occur quite isolated from the main bulk.

The many small granite dykes that traverse the slates behind the great coastal one, are coarse-grained veins, which form an irregular zone of injections; they give rise to peculiar caves along the sides of the rivers, and are sometimes pressed out and sheared with the phyllites. The main mass of granite cannot be very deep below the slates between the two great bosses, the George Town one and the Touw's River-Hooge Kraal one, and it appears that these small dykes are offshoots into the slate that took advantage of any cracks that were formed after the original intrusion.

On the east bank of the Touw's River, the great coastal dyke is faulted (Fig. 1); that portion forming the edge of the cliff dips seaward at about 50°; behind it at the top there is a de-

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tached block dipping at about 35°; and behind this again another one dipping at 15°. The section is obscured on the lower portions by débris and forest, and it is at first puzzling to account for the granite capping to the cliff; the rock rises out of the bush and scrub in the form of immense boulders. At the water's edge there is a small exposure of sandstone grit weathering red, hornblende schist in thin layers and white felspathic quartzites, the whole of these stratified beds dipping at a low angle seawards.

The shallow waters of the Lange Vley wash the base of the cliff further to the east, and beyond, the whole face of the Touw's River-Hooge Kraal granite towards the Lakes consists of these sheared rocks, gneisses, and felspathic quartzites.

Following the Touw's River up from the mouth one loses all sight of the granite after the initial wall of the great dyke is passed, and the river is seen to be cut in a plateau made up of slates, phyllites, and gritty rocks. Near the main road, however, the western end of the Touw's River-Hooge Kraal mass is seen on the right bank of the river.

The slates between the two great granite bosses are intensely sheared for the most part, but along the Kaaiman's River there is a great mass of sandstones and quartzites, which are indistinguishable from the Table Mountain sandstone; these, being of great thickness and hardness, have not been so much affected by the crushing as the softer argillaceous beds; nevertheless, they have to a certain extent participated in it. Near Pacaltsdorp, to the south of the main granite, there are similar quartzitic rocks, but along the Touw's River to the east they have disappeared. I am inclined to think that these are merely sandy beds in the Pre-Cape series, for had they been really beds belonging to the Table Mountain sandstone, it is hard to explain how it is that they became involved in a crushing which must have occurred before the deposition of that series. The quartzitic beds grade into the slates down the road to Kaaiman's Gat, but much of the junction has been obscured by the earth movements.

Kaaiman's Gat is an immense hollow cut in the quartzitic beds; the mouth of the river is of a type frequently met with in the Eastern Province, where two main rivers unite to form one common entrance to the sea. On the east the Kaaiman's River with a large tributary, the Silver River, drains a large portion of the Outeniqua mountains; after leaving the Table Mountain sandstone it emerges on an area of slates and phyllites of no very great weather-resisting powers. On the west the Kat and the Zwart Rivers draining a smaller area, skirt the northern border of the George granite, but they fall into a region of granite dykes, which form impediments in their course. The western streams, then, from their lesser drainage area and the harder rocks they have to traverse, have been unable to cut into the

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high-level plateau to such an extent as the eastern streams, and whereas the latter have been able to cut a moderately graded river bed for themselves down to sea level, the former, when they come to the sea, have the bed of their united waters still some 100 feet above the sea level; they therefore pour over a krantz as a magnificent waterfall. The swirl of the waters has cut a round-barrel-shaped hollow with straight sides, and the impact of the falling mass has excavated the bottom of the hollow many fathoms below sea level. The sudden change of strike in the coastal granite dyke at the mouth of the Kaaiman's River has evidently been the cause of these rivers selecting this particular spot at which to eat their way seawards, for the bend was produced after consolidation of the dyke, and the motion must have crushed the compact rock. All these rivers, the Malgaten, Gwaayang's, Schaapkop's, Molen, and Kaaiman's, have their beds, as they enter the sea, quite normal, and they do not occupy channels that have been excavated many fathoms below sea level at an earlier period, as in the case of the Great Brak, Knysna, and Keurboom's Rivers.

On either side, at Mossel Bay and Knysna, there are extensive deposits of Enon gravel, and the absence of this formation over the area under discussion points to an up-lift after the deposition of these Lower Cretaceous beds; then there was a general levelling of the coastal plateau, cutting to a flat surface equally the Cretaceous and older rocks. The whole drainage of this part of the country was re-distributed when the plateau began to rise, and these rivers in George date from that time; the Plateau may have been cut as far back as late Tertiary times, but it is certainly of no greater geological age.

The Touw's River-Hooge Kraal granite mass is nearly hidden by deposits laid down on the coastal plateau, and where these are absent, by deep weathering. Nearly the whole area is covered with grass and soil, and in the kloofs by forest. There are good exposures, however, of the granite on the western bank of the Touw's River, along the southern border, in a gneissoid state, and down the Zwart River which forms the boundary of the George and Knysna Divisions. It appears to be generally a white mica granite, without the tourmaline veins which characterise the George mass. On the southern border it joins up with the crushed gneiss dyke, and on the north, also, along the Olyvenhout's River, there is exposed a similar zone of crushed gneissoid rocks, with shear planes dipping at a very low angle to the north. The nature of the rocks along the Olyvenhout's River reminded me very much of the sheared zone on the south of the granite boss at Robertson, where the Malmesbury slates, thickly injected with granite veins, have been caught between the resistant boss on the one hand and the great Worcester-Swellendam fault on the other. North of the crushed granite there are slates, but so badly ex-

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posed that no boundaries could be seen; the whole of the river valley is densely clothed with forest; at the upper sledge-path drift there are some black carbonaceous shales.

Down the road to the Geelhoutboom River there are white sandy beds, and near the Karaatera River undoubted Bokkeveld beds. It is impossible to trace the exact boundary of the Hooge Kraal granite on the eastern end. Between the main road and Zwart Vley there are slates which I believe are Pre-Cape; towards the vley the whole country is covered with sand, and the river valley is hidden with forest, which is almost impenetrable. A short exposure of rocks occurs on the last ravine leading into the Karaatera River from the east; they form a jagged ridge of Table Mountain sandstone and slates, which again I think are Pre-Cape, occurring as they do on the underside of the dip; the Table Mountain beds dip to the south-west.

On the Zwart River there is a better exposure of slates on the south side of the granite, and a road has been cut along the side of the ravine from the farmhouse on the level of the Zwart Vley to Hooge Kraal on the high-level plateau, and thus we are able to get a glimpse of the country rock from underneath its covering of sand and forest. The slates are gently folded, but intensely sheared, and consist of slates, phyllites, sandy slates, grits, and quartzites. Near the top there are rocks weathering white, and resembling the white felspathic rocks of Victoria Bay, together with phyllites and grits. In among these there are several fine-grained granite dykes, and finally a large dyke of hornblende-schist. From the road one looks down into a narrow V-shaped gorge, 500 feet deep, clothed on both sides with luxuriant forest; at one place there is a small waterfall, and the rock appears from a distance to be granite, but I was unable to make my way to the place, and could not determine whether it was part of the main granite mass or a vein like those along the road.

As far as we know, these patches of slate and granite are the last of the Pre-Cape rocks in the Colony in an easterly direction. Mr. Dunn marks Namaqualand Schists at Hankey, along the line of mountains which would bring them in the same set of folds which expose the Pre-Cape rocks of the Cango; so far this district has not been surveyed. As regards the granite, however, the Hooge Kraal mass is certainly the last, and it is not till one crosses over into Natal that one again finds this rock. Coincident with this termination of the granite, there is a marked change in strike in the mountain chains: hitherto, following them from the west, they have run fairly due east from Worcester, but hereabouts they bend round the end of the granite and assume a direction distinctly south of east. This fact is clearly brought out on all small scale maps of the Colony; along the sea-coast, the actual corner of the bend can be pointed out, for it occurs at the mouth of the Kaaiman's Gat River.

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In the general structure of the mountains, also, there is a great change that becomes apparent in this neighbourhood. At Montagu Pass the folding is still intense, and the separate limbs are closely pressed together as if huddled against an immovable block; north of the Touw's River-Hooge Kraal granite the folding is inconsiderable. In the Long Kloof, there is a sudden widening of the folds, and whereas from the west there are only southerly dips to be noticed, east of the termination of the granite there are northerly dips.

These considerations have led me to think that the Touw's River-Hooge Kraal granite mass has not acted as a buffer to the folding that broke against it, like the George mass, but that it has yielded and turned from an original north-easterly direction to a more directly easterly one—that is, through an angle of 15° to 20°. If my reasoning is correct, then we must regard this block, not as one anchored to the great basement of the earth's crust, but as an immense horizontal tongue or offshoot from the main granite masses that underlie the sedimentary beds in the south-west corner of South Africa.

The great shearing that has taken place in the George granite would, on the above theory, be the result of the lateral stress, not sufficient to shift the whole mass of the granite, but tearing through the more superficial portions and producing the cracks which are now filled with the tourmaline veins. The great coastal dyke was crushed at the same time, and the constituent minerals re-arranged, while the sedimentary rocks behind it were metamorphosed. What was in front of the dyke, that is to say, in the forward side of the movement, we cannot tell, as all has now been removed by the action of the waves, but in all probability there were Pre-Cape rocks, such as we find along the lower course of the Kaaiman's and Touw's Rivers; the shearing and crushing that they underwent, by imparting a fissile character to the rock, rendered them no doubt easily acted upon by weathering agencies, and facilitated their removal by the wash of the breakers. I think it improbable that the present coast line along this portion of the coast has been determined by folding or faulting; such movement found relief further out to sea, and is consequently out of the range of possible investigation.

The Table Mountain Sandstone and the Bokkeveld Beds.

These two series form by far the larger surface of the area under discussion.

North of George Town, the Outeniqua mountains rise to heights of about 4,000 feet; the range is not a sharp escarpment, but consists of a high backbone, with long lateral spurs, between which there are deep, wide kloofs. The boundary be-

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tween the Pre-Cape slates and the Table Mountain sandstone is covered with soil and often with forest. There is a variety of the sandstone, produced by the covering of damp soil, which is so loose and friable that it can be cut with a spade; it is not argillaceous, but looks so like decomposed Malmesbury slates that one cannot tell the difference till one crumbles the material between the fingers. The decomposed rock has many coloured bands, red, pink, and yellow, and sometimes brown iron oxide streaks. Occasionally one sees hard centres which have not yielded to the softening, and quartz veins that traverse the rock are naturally unaffected. This rock is frequently found in the forest near the junction of the Pre-Cape rocks, and helps to obscure the passage from one system to the other.

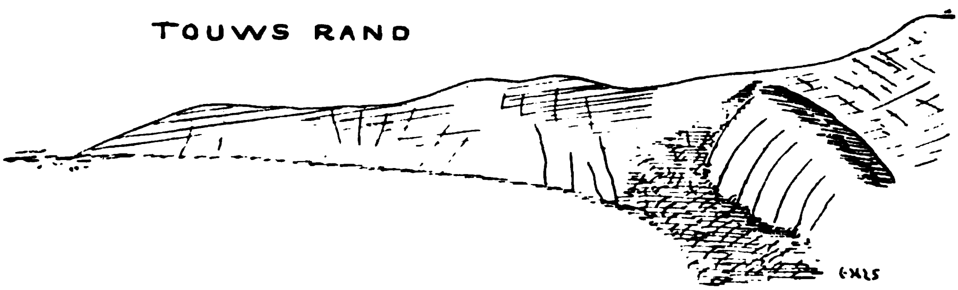

FIG. 2.—Touw's Rand, showing the projection of the Table Mountain sandstone to the south.

At Touw's River there is a portion of the sandstone jutting out southwards, called Touw's Rand; it is cut off on the east by an escarpment in which the strata are shown dipping south. Behind this projection there is a great wall of massive blocks of sandstone running eastwards along what is henceforward the general boundary of the Table Mountain sandstone (Fig. 2). Touw's Rand has been thrust forward between the two great granite masses, and apparently indicates the more pliant nature of the Pre-Cape slates as compared with the granite.

Touw's River, Deep River, and Zwart River have excavated very large, wide basins for themselves in the mountains, and there is a very remarkable difference in these to similar ones further west: in the latter one finds the rocks steeply and intensely folded, but here, at Berg Plaats, for instance, the beds are quite unaltered by secondary folding, and the strata sweep down from the crest of the range in one vast inclined plane.

At Millwood one enters again the folded region in the mountains; the beds are steeply folded with a strike that turns round to the south-east. I count five main synclines running in this direction, south of the mountains, in the coastal plateau between Knysna and Storm's River, and I think it will be best to describe

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each in turn, beginning from the westernmost. None of the synclines is a continuous, even trough, but there are broad cross folds, which raise the level of the fold, and where there are Bokkeveld beds included, these are repeatedly cut out on the surface by having been raised above the plateau level.

The first syncline includes the Rooi Kraal area of Bokkeveld beds, and probably also a succession of deep hollows in the Table Mountain sandstone, which are now occupied by deposits of Uitenhage age, which are of a later date. The true line of the syncline would follow up the Groot Kop's River, and come out at the south end of Plettenberg's Bay; the Uitenhage outcrops lie outside the axis of this fold, and will be described separately. The Rooi Kraal Bokkeveld beds occupy an area approximately four miles by six. On the main road they come in with great suddenness after the granite which one sees coming from George, and there is hardly space for the full thickness of the Table Mountain sandstone to exist between the outcrops of the two rocks, a fact which suggests hidden faults. The sandstone shows some remarkable parallel faults in the short cutting near the Karaatera River bridge, and slips of the inclined strata have been dropped twelve to twenty feet between vertical walls. The Table Mountain sandstone in most places ends abruptly on top, and one can see the exact junction between it and the overlying Bokkeveld beds, but at the Karaatera, and we shall again see, in the Knysna mountains, there are soft argillaceous-looking white beds, which are really decomposed sandstone, and render the junction very indistinct: we have already recorded the same fact from the bottom of the series where it overlies the Pre-Cape rocks in George, and the occurrence, therefore, seems to be due to infiltration of water rather than to original lithological difference.

At Rooi Kraal, or the post office, Barrington, the junction is not seen; the farm lies in the same level flat as occurs in the granite area on the west. Outcrops are confined to occasional quartz-reefs that project above the sandy soil, but these tell us nothing, as they occur equally in the sandstone and slate formations. If one follows the Little Homtini down to where it runs into the main Homtini, one can see fine exposures of slate-rock all the way; in the less precipitous side kloofs the slates weather in a manner very similar to the Caledon and Swellendam Bokkeveld beds, that is to say, they break down into greasy yellow clay with red stains. No fossils could be found here, except very small red patches, filled sometimes with a silky white fibrous mineral. Further down, the river runs in a precipitous gorge, with slate banks rising 300 to 400 feet: these show numberless large white quartz veins, which at Eland's Kraal are being prospected for copper. In an appendix there will be found a short account of the ore deposits in the Bokkeveld beds. As a rule, the beds dip 30° W. of S. at about 30°; the quartz

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reefs follow the strike of the beds, but dip about 45° in the same direction as the strata. Along the Homtini River the banks are very precipitous, and the lower slopes are densely clothed with forest; near the junction of the Little Homtini the sandstone again comes in, but I was unable to make my way to the actual spot. A little further down, below the embouchement of the Huis River, there is a wide bed of banket or conglomerate, which corresponds to a similar one found above the slate outcrop in the same river, and is evidently joined to it by a connecting sheet of banket passing under the slates. These bankets are very similar in appearance to the Rand auriferous conglomerate, only there is slate in the matrix; the gold content is very low, never, as far as prospected, ranging above 2 dwt., but then very little work has been done on these Knysna conglomerates.

The limits of the Rooi Kraal Bokkeveld area can be fixed within fairly narrow limits, but no boundaries can actually be traced, owing to the high-level plateau, which has been cut in them, being covered with soil; on Eland's Kraal to the south-west of the area there are large accumulations of blown sand.

Leaving aside for the present the hollows filled with Uitenhage beds, the rest of this first syncline is shown only in Table Mountain sandstone: the rock crops up out of the sand at Walker Point with a very irregular dip, sometimes to the south-west, sometimes due west. Following up the Homtini River, or, as it is called in its lower course, the Gouwkamma, from the mouth, there is deep sand till one comes to the drift, where some enigmatical gritty slates occur, unlike any of the formations in the neighbourhood; they are exposed in the road cutting near the river on the Knysna side, but one loses all sight of solid rock in a very short distance. Following up the river nothing is seen but an occasional krantz of sandstone projecting through the forest, until one comes to an immense chasm on the right bank. The river occupying this has apparently no name, but it runs into the Homtini just below Quarrywood. On the south bank there is an actual precipice of some 500 feet, but on the north bank the slope is about 45°, and a pathway goes through the forest up to Quarrywood.

Knysna village lies partly on Table Mountain sandstone and partly on Enon conglomerate. At the east end there is a large quarry, from which the building material for the fort was obtained, and in it there is a fine section of an anticline, each bed forming a semi-circular arch; it is a very good example of how hard quartzite like this can accommodate itself to strains, for naturally in the process of bending each stratum was stretched on the outer surface and compressed on the inner, yet there is no sign of cracking or crushing in the rock, nor are the beds separated by spaces. This fold is connected with the fault that lets down the Uitenhage beds to the east, and is, therefore, probably

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of a more recent date than the rock folds which we are describing.

Knysna Heads are cut in Table Mountain sandstone. The high-level plateau about Knysna village has been cut in Uitenhage beds, and these, from their easy disintegrating, have produced a wide hollow; along the sea, however, there is a ridge of sandstone at the normal height of the plateau, and the river cutting through this barrier has formed the picturesque heads.

The traces of the intense post-Uitenhage movements are visible in the sandstone in the extraordinary caves and natural arches that abound here. On the western head there is a very fine natural arch, over which a footway is carried, and on the eastern there are three immense caves facing the river (Fig. 3).

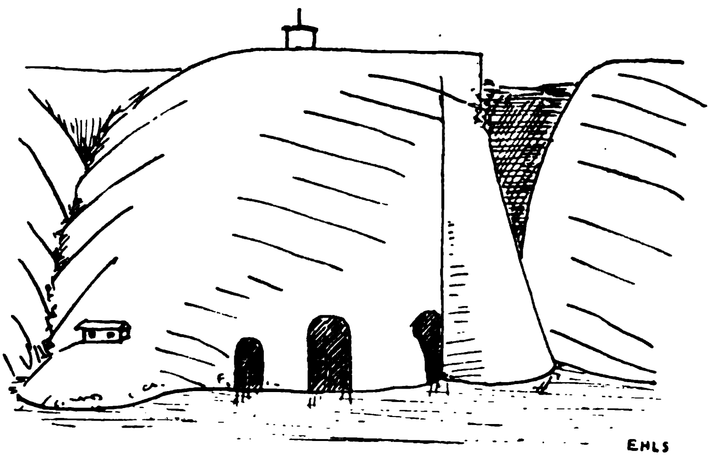

FIG. 3.—The Eastern Head, Knysna Harbour, showing the two chines formed along planes of crushing in the quartzite, and the three caves.

The eastern head also has two deep gullies in it which point to a crushing of the rock along planes which have been taken advantage of by flood water rushing down the hill side.

There is a small bay, called Barnard's Bay (Fig. 4), in the western head, and at sea level there are some rocks which look like coarse conglomerates: on closer inspection, however, the brown quartzite is seen to be actually a crush-breccia, and the rounding of some of the included fragments must have taken place *in situ* by the movement of the broken pieces over each other. Had these "autoclastic" rocks not been already described in Canada,[1] Lake Superior[2] and in the Isle of Man,[3]

[1] H. L. Smyth, Am. Journ. Sci., 3rd Ser., Vol. XLII, p. 331.

[2] Van Hise, Principles of N. American Pre-Cambrian Geology, 16th Ann. Rept. U. S. Geol. Survey, Washington, 1896, p. 679.

[3] Lamplugh and W. W. Watts, Crush Conglomerates in the Isle of Man, Q. J. G. S., LI, 1895, pp. 563-597. Lamplugh, Geology of the Isle of Man, Mem. Geol. Survey, London, 1903, p. 55.

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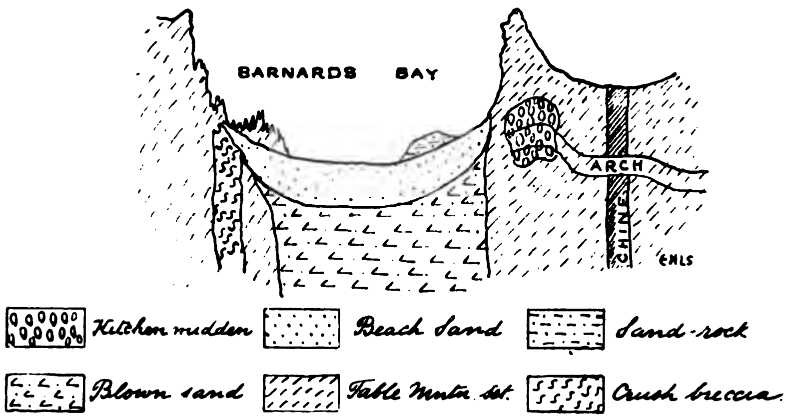

FIG. 4.—Barnard's Bay, Knysna Harbour, showing the position of the crush-breccia and the natural arch.

there would have been the material in these rocks in the western head of Knysna Harbour for establishing the fact that fragments can be broken from within a mass of rock and assume *in situ* all the appearance of water-worn boulders.

FIG. 5.—Arch and cave along the Knysna Coast, near Seal Point. Height of cliffs, 600 feet.

Further east along the coast there are several natural arches still standing boldly out from the cliff edge (Fig. 5), but a great many more have fallen, and the whole coast along here is studded with jagged rocks, among which the breakers are always

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surging. At the mouth of Knysna River these isolated rocks extend some distance out to sea, and make the entrance to the harbour exceedingly dangerous.

The old jetty at Knysna is made of slate, and until I heard the history of this I was very much puzzled to account for it, for I could find no quarry from which it could have been obtained. Ottrelite schist is said to occur somewhere to the east of Knysna, but I could not find the place; possibly there may be some down the Noetzee River. The Knysna jetty, however, was built of Malmesbury slate, carried in ballast from Cape Town. On the extreme end I also found granite, gneiss, vesicular lavas, and olivine basalts, together with white quartzite; this is also evidently ballast thrown out, but I could not hear anything about it; on the new jetty, however, there are curious granite and gneiss rocks, which I learnt definitely came in ballast in the S.S. Ingerid from Europe. Similar rocks are found strewn on the salt meadows on the western side of the harbour.

The second syncline starts somewhere to the west of Millwood, and after becoming unrecognisable for a considerable distance in the mountains, it can be again noticed along the Bitou River, though the valley in which this river runs is now for the most part occupied by Uitenhage beds, and the basin widened by movements much later than those which produced the original trough.

The main interest of this fold centres in the gold reefs which traverse the rocks in the Millwood area; in the appendix to this report will be found an account of them, with what appears to be the most rational view as to their gold content. The reefs run with the strike of the rocks, east-south-east, with a dip usually greater than that of the sandstones, and are similar in this respect to those along the Little Homtini River, where they occur in slate rock. In the sandstone, however, they have a more irregular course than in the slate, and tend to thin and widen out, and break up into stringers.

This fold is lost in the mountainous country to the east of Millwood. Near Plettenberg's Bay the edge of the coastal plateau is made of slates belonging to the Bokkeveld series, and these were probably in their present position before the Enon conglomerate was let down, and thus belong to the original fold. On the south side of the Bitou River two patches of slate appear through the conglomerate, one at sea level near the mouth of the Keurboom's River, and one in the hill behind.

The third fold was referred to in the Report on Knysna, but its western end was not traced. It is a double fold, for there are two narrow bands of Bokkeveld slate running parallel. A very thin slip is noticed on the Kruis River, west of the main road from Knysna to Uniondale, but it is not till some way down towards Paarde Kop that the rock can be at all well seen. The slates form a shelf on the south bank of the river, the bed

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of which is cut deeply in Table Mountain sandstone; they cross the Keurboom's River above the terminal straight portion, and run out to sea near the Groot River mouth. At this last point there is a marked change of strike from east-south-east to more nearly east, and these slates are picked up again, forming a ledge below the precipices of Table Mountain sandstone for a considerable distance along the Humansdorp coast. They are last seen just east of Storm's River mouth. The sea face of the cliffs here is covered with bush and forest, and about half-way down, or at an elevation of some 300 feet above sea level, there is a break or ledge formed of hardened slate (Fig. 6); the rivers that come off the high-level plateau cut through the Table Mountain sandstone, forming narrow ravines, but they end in the forest on the ledge, and the water must percolate through the almost vertical strata, and thus find an outlet to the sea, for

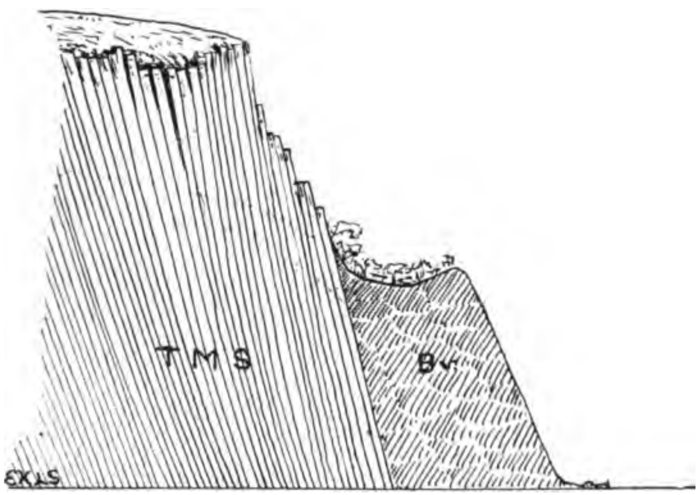

FIG. 6.—Section to the west of Storm's River mouth, showing the sea-cliff of Table Mountain sandstone (T.M.S) with the ledge formed by the Bokkeveld beds (Bv.).

there are no channels that run out of the slates along all this coast. According to fishermen, there is a submarine plateau that begins somewhere near Aasvogel Point, the edge of which is fairly well defined, and is well stocked with fish; off the mouth of the Humansdorp Groot River there is a sunken rock some two or three miles out to sea, which, though never at the lowest tides appearing above water, nevertheless is too near the surface for boats to pass over it, and in the calmest weather there are constantly breakers over it. I think it very probable that this plateau is formed by the spreading out of the Bokkeveld slates as all along the coast the Table Mountain sandstone dips very steeply seawards, as it does at Storm's River mouth, for instance,

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where it clearly dips under the slates. The strike of the Table Mountain sandstone is continuous all along this coast, except for an occasional cross thrust, which brings the strike exactly east; this change of strike can be well seen at Seal Point and at the mouth of the Humansdorp Groot River (Fig. 7). Nothing very definite can be said about this supposed plateau till the shore is surveyed, but we have here all the factors that go towards forming a plain of marine denudation, namely, a large area of more or less soft rock exposed in a precipitous cliff to the full fury of the South Atlantic breakers. Portions will be constantly falling down, owing to the loosening of the rocks at

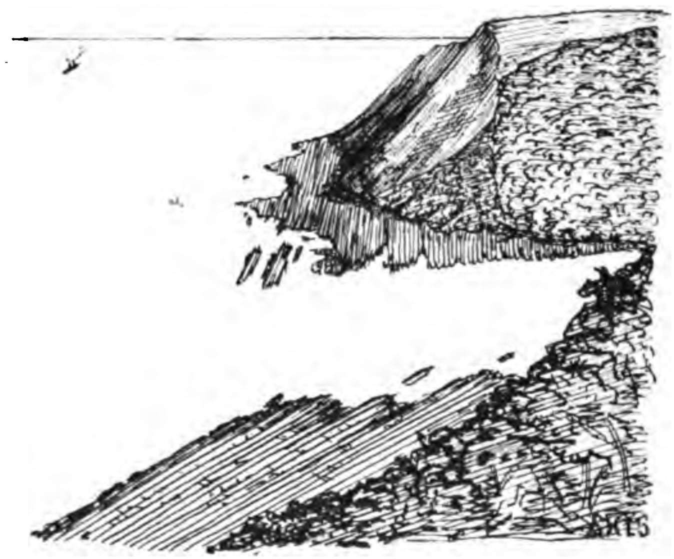

FIG. 7.—The mouth of the Groot River, Zitzikamma, showing the change in strike in the Table Mountain sandstone.

the bottom of the cliff by the pounding of the waves. These will be washed about in the surf, and will grind the sea-floor; not till this is reduced below the level of violent motion in the water will denudation cease. After all the slates have been removed from the face of cliff, the sandstone behind will naturally be attacked, as is the case east of Storm's River, but the rate of the reduction will be very much slower. It is, however, an indication of the newness of the high-level plateau, that the slate west of Storm's River has not yet been entirely swept away. Parallel with the western end of this outlier of Bokkeveld beds there is a strip of slates heading in the steep-ended kloof above which the road to De Vlugt runs; at the nek between this and the Kruis River valley there is a small shop and accommodation house, known as "Monk's." A small fold lets a

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strip of slate from the main mass in to the hill side on the south, but until the Keurboom's River is reached nothing definite can be seen in the valley, owing to the covering of sandy soil. The Keurboom's River runs down this slate outlier, and forms characteristic neks of red iron-stained rock; further down, the valley becomes very narrow, and finally the Bokkeveld beds get pinched out (Fig. 8).

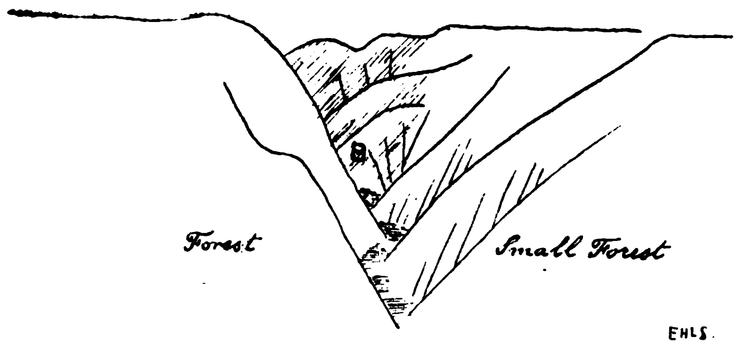

FIG. 8.—The valley of the Keurboom's River, showing the steeply dipping Table Mountain sandstone, and the end of the Bokkeveld beds (B) looking west from Paarde Vlakte.

The road from Monk's descends from the high nek to the Diep River; just before reaching the bottom the road crosses a thin band of slates, unmistakeably Bokkeveld, which, however, plunge into the steep hill side on the east of the river, and are enveloped in the Table Mountain sandstone. On ascending the hill on the north of the river, there is a great exposure of soft white, chalkey-looking sandstones, which I think belong to the Table Mountain series, but very near the actual top of the series. One is very much puzzled in a country like this as to where one is at any particular spot in regard to the rocks, as, for instance, a little further on, along the Assegaai River, there are again these soft sandstones, but here I regard them, having in view the general arrangement of the beds, as belonging to the shale band, near, but not actually at the top of the Table Mountain series; this bit of shale band is connected with the strip on Kykorie, which was referred to in last year's Report, p. 53, as being compressed in the bend which the strike of the rocks here assume.

Nothing very definite could be seen in the valley marked by the Deep River soft beds until, following the strike, one comes out on Jackal's Kraal. Here there is a wide flat formed of Bokkeveld slates, which cross the Palmiet River on to the Paarde Vlakte, at Jantjie's Stadt. The whole of the Paarde Vlakte is covered with sour grass, except where these slates come in, and their presence is very clearly marked by the sweet grass that grows upon them.

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The section (Fig. 9) along the Palmiet River finally sets at rest the puzzling phenomena of a strip of Bokkeveld beds, running with the strike of the rocks, but with the underlying Table Mountain sandstone dipping away from it on both sides, as if the slates belonged to an inlier of older rocks, instead of to an outlier of younger ones. At the Groot River, further to the east, this fold brings down the Bokkeveld slates again, and it was here, on a former occasion, that the same anomaly was noticed.[1] The Palmiet River section sets all doubts finally at

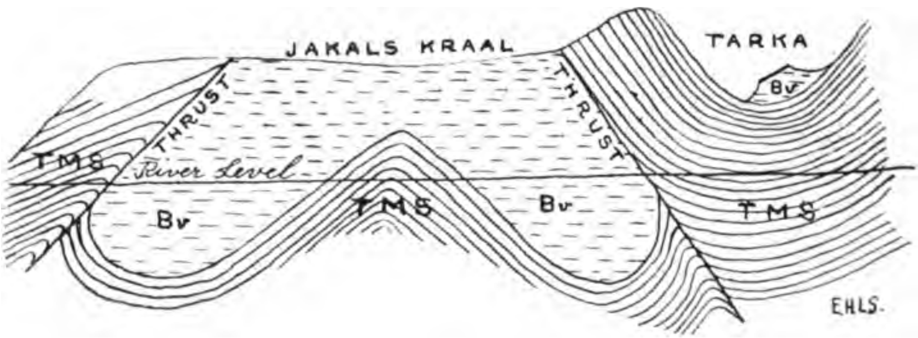

FIG. 9. –Section along the Palmiet River, showing Bokkeveld beds with Table Mountain sandstone dipping away from them on either side.

rest on this point, for just above the river level there is an anticline of Table Mountain sandstone that rises to the east, and finally widens out, so that the strata of which it is composed join up with the general sandstone beds of which Paarde Vlakte is made. The Table Mountain sandstone dipping away from the slates, likewise joins up with these strata as it is followed over the river to the east. The anamalous dip is explained by an anticline on either side of the slates originally inclined towards each other; these then gave way along their axes, and the outer limbs were thrust upwards over the inner ones, as represented in the diagrammatic figure. On the north side of the central anticline, between the sandstone and the slates, there is a reef of heavy, black, iron-cemented rock, which looks very much like an igneous dyke, but which is due to the deposition of iron from solution.

The last of the synclines met with in the district form the De Vlugt valley. It is occupied by Bokkeveld slates, which are cut to a level about 600 feet above that of the Keurboom's River. The river comes down the valley out of the Long Kloof, as described in last year's report (p. 54); about seven miles east of De Vlugt it suddenly abandons this valley, and cuts a tremendous poort through the ridge to the south, turns into the next

[1] Ann. Rept. Geol. Comm. 1899, Cape Town, 1900, p. 57. See also the same in Baviaan's Kloof, ib, 1903, Cape Town, 1904, p. 127.

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slate valley, along which it flows westwards again; cuts through another ridge of Table Mountain sandstone, and finally runs into another slate valley, down which it flows for a considerable distance. This remarkable winding can only have taken place provided that at one time the whole of the ridges and valleys that we now see were planed down to a common level; we can then imagine that where the river takes its first great bend, an accumulation of gravel rolled down from the mountains behind, blocked the course, and turned the river southwards, for there is nothing in the solid geology of the country to prevent the river from flowing down the slate valley right away to the Palmiet

FIG. 10.—View from Paarde Kop, overlooking the Keurboom's River Valley. In the distance are the Outeniqua Mountains; in front of these is ridge upon ridge of Table Mountain sandstone, sometimes separated by a valley filled with Bokkeveld beds, but each is cut down to a general level, the remains of an old peneplain.

River. Beyond what is known as Dwaas Nek, or the bank of slates which divides the waters of the Keurboom's from that of the Palmiet River, there are extensive flats of sweet veld. Near the main channel of the latter river, the syncline comes abruptly to an end, the Table Mountain sandstone being turned up round the slate like the bows of a boat.

The sudden ending of these slate valleys on a definite line is due, I think, to a broad fold, that has buckled up the land about here in a north-easterly direction; the movement probably took place at the same time that the Uitenhage deposits were let down into their present positions, and was not part of the great mountain building folds; it was again long previous to the

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cutting of both the lower coastal plateau, of about 700 ft. elevation, and of the higher one, of about 1,500 ft., which is now represented by the crests of the ridges south of De Vlugt (Figs. 10 and 11.)

FIG. 11.—View from Paarde Kop (2,397 ft.) looking east, showing the break of the 1,500 ft. plateau into the 700 ft. coastal plain. In the distance there is (*1*) Krakeel River or Peak Formosa (5,497 ft.); (2) Witte Berg (3,500 ft.) just above Forest Halt; (3) Spitz Kop (2,500 ft.) and (4) Zoet Kraal (3,143 ft.).

At the extreme east end of the Knysna Division there is a narrow strip of slates along the main road, folded in with the sandstone, which has very high dips, and is actually vertical on the north side; on the south side, the sandstone dips south, or away from the slate; and from the nature of the fold, this particular strip of slates may belong to the Jantjies Stadt-Groot River fold. The slates are well exposed in the drift over the

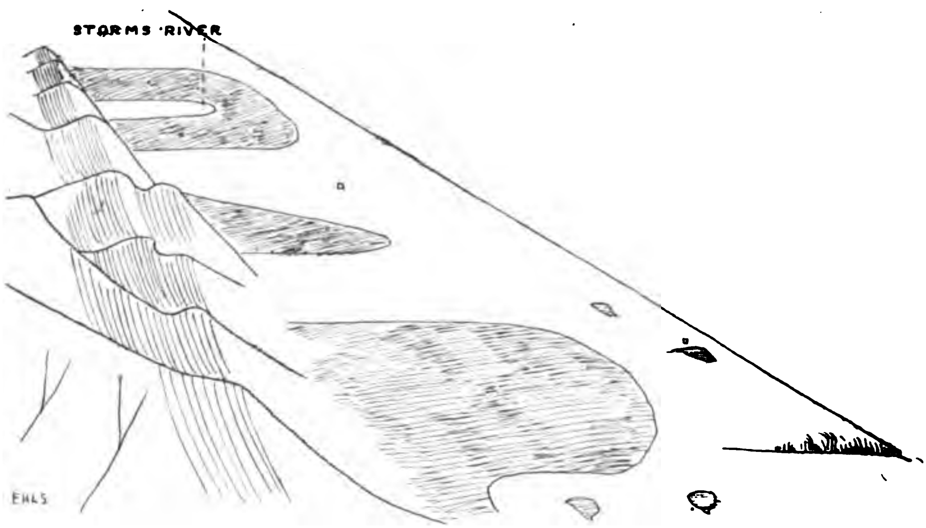

FIG. 12.—The Coastal Plateau in the Zitzikamma, looking east from the top of Coldstream Peak. The shaded portions represent forest. On the left the Table Mountain sandstone is seen, dipping steeply sea-wards.

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Blue Krantz River, and indeed the perpendicular walls of blue slate on the east bank give the river its name. The slates run a short way to the east, along the Hawthorn Kloof, but the valley is densely wooded; on gaining the level of the coastal plateau, there is nothing but sour veld to be seen, showing that the rocks beneath are Table Mountain sandstone.

The coast plain is here almost a desert, though there has recently been built a fine sawmill, to deal with the timber from the adjoining forests, and one house besides the forester's has been erected (Fig. 12). At Storm's River, however, there is a

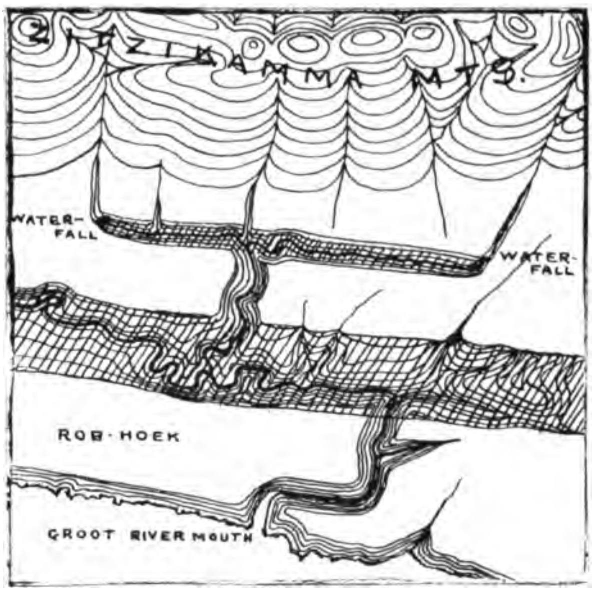

FIG. 13.—Sketch-map showing the two outliers of Bokkeveld beds, let in among the Table Mountain beds of the coastal plain. The area of the Bokkeveld beds is shown by the cross lines.

fairly wide strip of slate, the west end of which is hidden beneath deposits on the plateau, and by forest in the kloofs. In the Storm's River drift, however, good sections are to be seen. The slates can be picked up all along the same strike, namely, about 12° south of east, forming a gap, as it were, in the plateau, for the rocks being easily attacked by weathering agencies, have yielded readily, and the rivers that traverse the coast plateau have cut deep channels in this strip (Fig. 13). On the south, the plateau is of the normal height, and forms a ridge bordering the sea; it is very difficult of access, because of this slate valley on the north, with its deep forest-clad ravines, and the treacherous drifts across the rivers; while its length is inter-

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cepted repeatedly by precipitous walled ravines, through which the streams coming out of the depressed slate area reach the sea.

The most notable of these gorges is that of the Storm's River; on the coast, there is a little harbour, where boats and lighters shelter in a bay cut in the Bokkeveld slates, while a wire-rope connects the half-way ledge of slates with the sea level; small coasting steamers can anchor off the bar of the river, and receive their cargo from the lighters. Putting off from the harbour in a boat, one crosses the bar, and then enters this wonderful gorge; the actual height is, I think, rather over 600 ft. than under, and the walls are not only perpendicular, but actually overhang; at one place a tree flung across the ravine would form a bridge from side to side.

The eastern end of this strip of Bokkeveld beds lies further in the Humansdorp area than I was able to reach. North of it, near the Karedouw Pass into Long Kloof, there is a very narrow strip of slates, parallel with the larger one. (Fig. 13.) It is pinched out on either side, but on the east comes in again as a wider strip; the length of the first part is about five miles. The streams that come down from the Zitzikamma mountains run for a short way over the coastal plain, and then plunge into the deep gorge that the soft slates have allowed to be cut in the plateau, and many picturesque waterfalls occur; it is a remarkable sight, when riding over the grass-covered flats, to suddenly see a great waterfall plunging into what appears to be a great hole in the ground, for this transverse gorge is so narrow that one does not perceive it till one is actually at the edge. Some of the rivers, however, end in marshes at the edge of the ravine, and the water trickles away through joints in the rocks.

There is a magnificent valley, forming the head waters of the Palmiet River, which is locally referred to as Zoet Kraal, though the farm of that name only occupies part of the area. It is shut off from the Long Kloof on the one side, and from the coast plain on the other, by very steep mountains. The soil in the valley is entirely sour, but there are some softer beds in the centre, which appear from a distance to be slates, but they are merely soft beds in the sandstone; probably the Bokkeveld beds were represented, but they have now been removed. The valley is a syncline, and on the south side there is a magnificent anticline, shown boldly in the side kloofs of the mountains; looking east from the high peak above Coldstream, one sees this fold running far into the distance, with serried rows of hogs' backs marking the southern limb. The Zoet Kraal syncline rises rapidly, and on the southern banks of Peak Formosa the strata, bent into a trough form, can be plainly seen; beyond, the syncline becomes lost, and the south limb of the anticline closes in with the north limb of the syncline, the two forming the Zitzikamma and Long Kloof Mountains respectively (Fig. 14).

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FIG. 14.—Folded Table Mountain sandstone scenery. View of the Outeniqua and Long Kloof Mountains, looking east from Coldstream Peak. The syncline that forms the valley of Zoet Kraal is seen rising on the left. The row of hog's backs, on the right, belong to the south limb of an anticline running 10° S. of E., that is, along the general strike of the beds on the coastal plateau about there.

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The range eventually dies out near the Humansdorp coast, becoming simpler and simpler in structure as one follows it eastwards, although there are disturbances across the strike of the rocks which tilt the mountain mass in the direction of its length; such an one can be seen at Karedouw Pass, where the mountains on the east have been lifted bodily above those on the west, and the road runs in the gap excavated in the crushed rock along the fault. The main road to Humansdorp from the Zitzikamma* passes round the end of the mountains, a point which is interesting in view of the immense length of the coastal mountain-chain; beginning in Bushmanland, we have traced it south, as the Bokkeveld Mountains and Cederbergen, to the great knot of mountains about Worcester, and thence eastwards, as the Langebergen, Outeniqua mountains, and the Zitzikamma mountains; on the north, where the mountains end, there is open country between the coast and the interior, but at the eastern termination, on rounding the point, one is faced with a vast complex of ranges, that bars the passage to the Karroo.

THE UITENHAGE BEDS.

The Uitenhage deposits in the area with which we are dealing were referred to in the 1899 Report, and there are one or two points which I wish to add to the description published there.

In the first place, there are two areas where the Uitenhage beds are exposed, which were originally mapped as drift sand; the one is to the east of Knysna, and the other opposite the village, at a farm called Brentford.

The first one is completely covered with loose sand, and, indeed, is itself made up almost entirely of sands and clays; only on the south side can the conglomerate be seen dipping under the looser rocks on top. The new railway which is to run from Knsyna to the main forest exposes some fine sections of the loose sands and clays in the cuttings, and without these, it would have been impossible to discover these deposits. One deep section exposes an alternate series of reddish and brown sands and red and apple-green clays; further towards the conglomerate, some sandy white clays and even a pure white kaolinitic clay are seen. Between these two points the cuttings have exposed a grey shale, with indistinct plant remains; these were so strikingly like the Herbertsdale shales, containing *Cladophlebis browniana*, that I eagerly searched for the parent source of the rubbish on the embankment, but I was unable to find the rock *in situ*. The whole of the beds dip north-north-east at about an average dip of 15°; they abut on a hidden wall of Table Mountain sandstone, formed by a fault-face.

In the centre of these sandy Uitenhage beds there is a remarkable development of ironstone, formed by spring water

[1] A Hottentot word probably meaning "rushing waters."

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carrying iron in solution, the mineral having been deposited, and now cements the sand grains into a hard rock. The springs at present issue behind the ironstone, but only in a small trickle; from the formation of the ground, the fault, and the loose sandy rocks filling in a deep basin, it is very probable that if these springs were opened up, a very large supply of water could be obtained; it is to springs in the same position that we look for our greatest supply, but the only one properly opened is the Uitenhage spring.

All over the high plateau about here, behind Concordia and on either side of the main road, near the Paling River, there are thick deposits of red sand, that merge towards the coast into the ordinary yellow drift sand; from the sections exposed in the new railway, I very much suspect that these red sands in part are Uitenhage beds, but it is impossible to say if they are in the position in which they were originally laid down, or whether they have been resorted by the wind.

The Brentford patch of Enon was passed by me again and again, but always mistaken for recent deposits, that is, sand-dune sand cemented with lime. Mr. J. Rex, however, showed me a Trigonia from the locality, and Mr. Rogers, on a recent visit, made an examination of the place, and proved the existence of fossiliferous marine Uitenhage beds.

There is a feature in the Enon conglomerate exhibited in the road cuttings down the Phantom Pass which calls for remark. The gravel beds are usually sorted out in regard to the size of the pebbles, large ones being collected in one zone, smaller ones in another, and sandy beds in a third, and so on; but in this particular place all varieties and sizes are tumbled together, in defiance of the laws of gravity. How came such a mixture of large and small boulders to be distributed through a sandy matrix? There is no possibility of invoking ice-action, but the mud-rushes in the Alps give some clue as to the origin of this. The rocks in high altitudes become disintegrated by frost and variations of temperature, and strew the hillside with debris; when a strong fall of rain occurs, this loose material absorbs the water until it can hold no more. At this point the whole mass begins to move—mud, sand, rocks, and water—and gathering impetus, flows down the hillside with a prodigious roar, the solid rocks grinding over one another, and the sand swishing over the surface of the ground[1]; observers have stated that a mud-rush of this kind resembles a lava-flow very closely.

When the Outeniqua mountains were first raised from the original plain of deposition in Jurassic times, they must have been enormously higher than they are to-day; it is true that their base was much lower, as we see from the old levels of denudation at their foot, but for all that, their mean height above

[1] P. Demontzey, Reboisement des Montagnes, Note A, Paris, 1882.

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sea-level must have been quite twice as great as now, that is to say, they rose to a maximum of over 10,000 ft. Such a height would give the excessive variations of temperature necessary to produce intense crumbling of the rocks exposed on the surface, and such a range bordering the sea would cause excessive rainfall. Both these conditions for the production of mud-rushes would, therefore, have been present, and the material when it came to rest would show the peculiar features which we see in the Enon conglomerate in the Phantom Pass.

NOTE.

Since the above was written, a most interesting mud-rush has occurred near Cape Town. The month of June set in very wet; there were recorded, from the 4th to 10th, the following readings:—.25, .50, 1.03, .87, .57, 1.35, 1.63; total, 6.20 inches for seven days. On the 11th it was still raining, and all the previous day the houses on the high-level road at Clifton were threatened by an inundation from the water flowing down the ravine behind them. There was a dam some distance behind the houses, strengthened by a row of full-grown pine trees, which turned the water into a furrow, and led it away from the little settlement. All night long men were stationed to see that the dam held, and everything seemed safe when morning broke. The workers then retired to the house of Mr. S. B. Mills to refresh themselves after their night's labour in the soaking rain. At ten o'clock on Sunday morning (the 11th), some people staying in the hotel below, came up to see how the people above were faring. As they came over the high-level road, they heard a dull rumbling, and shouted to the inmates of the houses to save themselves. The latter rushed out, and immediately afterwards an avalanche of water, mud, and trees swept down the ravine with the roar of a thunderclap. The liquid mass struck the row of pine-trees by the dam, and felled one of the central ones, and then swept over the little patch of garden ground below. The soil of this garden became liquid to a great part, and helped in the destruction; a big oak tree was carried away by the onset, and its roots plunged into the midst of Mr. Mills' house, carrying away the walls. The liquid mud then poured through the gap where once the building stood, over the high-level road, and down the steep slopes of the mountain side; some even reaching the low-level road by the Clifton Hotel.

The ravine begins some distance above the pipe-track, along which water is conveyed from the Kloof Nek to Sea Point. There was formerly a fairly straight main channel, with a side valley on the left; on the right bank, there was a steep cliff of soil and boulders, which has now been cut into, and a new lateral ravine has been formed. In the early part of the summer

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just past, the veld had been burned, and the woody *Protea* and other bushes had been reduced to blackened stems; the fresh grass had just begun to sprout at the time of the accident, and had not yet gained any considerable strength. The mud seems to have first begun to loosen in the side valley on the left and, collecting into a mass, to have flowed down with great velocity; the rush entered the main valley with a bang, for the steep wall on the right is splashed high up with the black mud, and then it must have torn down the ravine, sweeping everything before it. The soil on this slope is entirely composed of decomposed granite, and it is a curious fact that it is only the surface soil, blackened with the charcoal of the burnt bushes, that went to form the mud, a fact which perhaps explains the occurrence of granite debris along the slopes of Camp's Bay containing a small percentage of carbon, a deposit which it was attempted to exploit as a carbonaceous gravel. The only trace where the sub-soil has given way is on the steep wall above the junction of the top left-hand valley with the main one; here a portion of the debris slope has been torn away, leaving a clean yellow surface exposed. Large granite boulders, such as lie about the surface, were carried down by the rush, some coming to rest only at the very door of the Clifton Hotel, but the main bulk of the material was pure granite wash.

The occurrence was of very small dimensions, but the force of the rush was concentrated by the narrowness of the ravine; had there been a wider valley, no destruction would have occurred, as may be seen on the down-side of the high-level road, where the mud distributed itself harmlessly over the surface of the ground.

The occurrence is of special interest, as illustrating the nature of liquid mud rushes generally, be they formed by the accumulation of water in loose soil, or by the condensation of steam in volcanic scoriæ and ashes, and also the probable origin of the carbonaceous gravels of the Cape Peninsula; but it also explains the many valleys in and around the slopes of Table Mountain, which are filled to a great depth with loose sandy soil, evidently pure granite wish, even though the rock cropping out on the sides of the valley are such as could only afford a clayey soil, that is to say, belong to the clay-slates of the Malmesbury beds.

There are in the valley some boulders ten to twenty feet in diameter, composed of granite; these seem to menace the little settlement, one house of which is built actually under the shadow of one of these gigantic boulders. High up, where the main ravine forks, there is a large boulder, which has come down from above, but it appears shed from the parent rock; these other boulders resting on soil are fairly safe, as their immense

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weight would prevent the absorption of water by the soil under them. In the Enon conglomerate, which is in part derived from mud rushes of the kind referred to, there are never very large boulders like those of Clifton, and I think we can safely say that something more than soakage of water would be necessary to dislodge them.

THE SUPERFICIAL DEPOSITS.

Where the Kaaiman's River in George enters the sea, the coast changes; on the west, there are precipitous granite cliffs, rising 600 ft. directly from the sea, with but a narrow ledge of surf-cut beach, strewn with fallen boulders, and interrupted by pinacled, jagged crags, round which the waves are continually boiling; there are no sandy beaches along this shore, except in one or two small bays. East of the river's mouth, the same sea-cliffs are seen, but in front of them has been piled an immense accumulation of blown sand.

Blown sand on this shore is produced by the communition of shells, which are thrown up by the sea, washed about by the ebb and flow of the tide, till they are broken into tiny fragments, and thus become small enough to be caught up by the wind. Against a steep cliff, the sand does not accumulate in an inclined slope unless the prevailing winds strike inland at an acute angle; where they come full upon shore, there seems to be a back eddy, which causes the sand to build up a ridge with a valley between the sea cliff and itself. When it rains, this hollow becomes sodden with water, and vegetation springs up, and it seems that the back-eddy tends to push the crest of the ridge seawards, while the off-sea breeze piles up more sand; so it comes about that the ridge grows bigger and bigger, and advances outwards, while behind it is formed a marshy level tract, covered with bush and water-loving plants.

All stages in this process can be seen along the shore between Kaaiman's River mouth and Gericke Point; but in the aggregate, this action, having gone on for a very long time, has built up a mass of sand, 600 to 800 ft. high, along the shore, and left behind it a low tract, now occupied by a long string of Lakes, or Vleys, as they are known in South Africa.

First, there is a long narrow lagoon, forming the mouth of the Touw's River; connected with this there is the Long Lake, divided into two portions, with a picturesque island rising from the waters of the western half; then, entirely separated from the others, comes the Round Lake; then the Black Lake, a very extensive tract of shallow water, with long, winding branches;

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and finally, there is the Green Lake. All these lakes are more or less brak; they are shallow, depths of 15 to 20 feet being exceptional; while, as a rule, people can wade over the greater part of them. Each, however, has its own peculiar characteristics. The first portion of the Long Lake is bounded by high cliffs of sand, which almost shut it off from the other portion; the road, too, on the south side is carried through the water, there being no ledge beneath the cliffs; the island is steep, and has barely ground for a small house, which looks as if it is fastened to the south side. The eastern half of Long Lake lies in more open ground, and there are farm lands all round its margin. Round Lake lies also in among cultivated ground, and when the water is low, there are extensive tracts of salt meadow land, which carry large herds of cattle, horses, and ostriches. Black Lake is a dismal swamp, bordered with stretches of black, stinking mud on the south; but on the north side it is closed in with steep sand cliffs, covered in part with grass, and in part bare of all vegetation; the constant burning of the veld is tending to make the whole one barren, sandy waste. The great sea-cliffs of sand that have bordered the shore from the Kaaiman's River break away at Gericke Point, and the gap has been healed by the accumulation of sand of a more recent date; the blocking of the outlet of the Black Lake has caused the water channel to wind in among low sandy flats. On the east of the Lake, one enters a wilderness of sandhills, reaching at the Belvedere beacon a maximum elevation of 912 feet above sea-level, but the whole thickness from above sea-level to this point is probably in part made up of older rocks underlying the sand. Green Lake lies in among grass-covered hills, and on the borders there are small patches of forest; the south side is closed in with steep sandhills, rising 600 feet above the lake, and densely covered with forest, which every year is being encroached upon by veld fires. The margin of this lake is occupied by extensive marshes, on which grow two kinds of reeds, a dark, blue-green sedge and the lighter yellow-green matjes-hout, a sort of papyrus. After the depressing bareness of Black Lake, it is very astonishing to come upon this beautiful lake, with the green border and forest about it, though the Black Lake seen from the mountain tops behind, for instance, from Devil's Kop, looks as fair a sheet of water as one could imagine. The water of the lakes varies from almost sweet in the Round and Green Lakes to pure brine in Black Lake, though the quality is dependent on the amount of rain that has fallen in the district; after drought, all the lakes become brak.

The sand tails away on the upland plateau behind Black Lake and Green Lake, and brings a percentage of lime into the sour soil, rendering it sweet; hence these sandy patches are more thickly populated than the rest of the country. The lime is often dissolved out of the sand, and forms beds of pure white

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lime, which is quarried and burnt for building purposes. Otherwise, there is not the same formation of hard sand-rock as in the Bredasdorp downs, which was produced by the cementing of the grains by dissolved and redeposited lime. On the sea-cliffs between Kaaiman's River and Gericke Point, the sand looks like a rock, but is quite soft, although it has been cut away by the wind till the face of the cliff is quite perpendicular. The extraordinary false bedding in this sand is beautifully exposed in the cliffs, and endless examples can be photographed.

At Gericke Point a portion of the cliff has become separated, and stands out in a bold promontory, in which the false bedding is very well shown. The sand rock goes below sea-level here, and is cut into several plateaux; the higher, on which the headland stands, is not covered by water at ordinary tides; the water, collecting in the pools, evaporates, and leaves behind small deposits of salt, which is collected for the local fishery; the lower plateaux are always submerged, and the surf beats furiously against the edges of the intermediate ones, showing how greatly this soft sand-rock has become consolidated.

Similar ledges of sand rock follow the coast all along where the sand dunes are, not only here, but in Bredasdorp; west of the mouth of the Touw's River, they are never exposed, but their presence can be inferred from the numerous fragments cast up on the shore. The surface of the ledges is exceedingly rough, and is formed by hardening of the rock along cracks that traverse the rock in every direction, so that more or less hexagonal portions are enclosed by them; between these cracks the sand is softer and is easily removed, leaving the infilled cracks now standing up like little walls; and where two or more cracks meet, a little pinacle is formed. Sometimes the cracks are further apart, and leave large shallow pools, enclosed by low walls.

The question of these sunken areas of sand rock is one of great importance, for it implies a sinking of the ground, whereas we know that this sub-continent has been subjected to considerable elevation during comparatively recent times. I was at first puzzled to account for the hardening of the rocks, and thought that possibly this might have taken place in the ordinary loose sand that is washed up on the shore. The character of the rock, however, shows unmistakably that it is the wind-blown sand, consolidated before being sunk, and subsequently hardened by sea-water. That it can be hardened when below sea-level better than when exposed to the atmosphere seems paradoxical, but I think the process can be explained in the following manner. The sea-water contains carbonic gas, and under ordinary circumstances, retains this, and dissolves a little of the lime of the sea-shells. When the water

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is left at the ebb lying upon the sandy rock, it is heated by the sub-tropical sun, and the gas is driven off and the lime in solution is deposited over and in among the sand grains, thus binding them together.

I have read with attention the description of the stone reefs of Brazil, which occur on a coast bearing many striking resemblances to the one we are describing; these are beaches consolidated by the deposition of lime, and, according to Mr. Branner as not due to the sinking of the material. This author, however, admits that wind-bedded sand occurs below tide-level on Fernando de Noronha, an island not far from the Brazilian coast. At Port Elizabeth, on towards Cape Reciefe, there are typical stone reefs, that is to say, boulders and sand cemented together with lime, with oyster shells and other marine organisms imbedded in the matrix; and if the sand rock could have sunk on the George coast, it is probable that a like sinking occurred at Port Elizabeth, and in a similar manner, if sand-rock sank at Fernando de Noronha, it seems likely that the same fall may have taken place on the Brazilian coast. In Brazil, Branner records both depression and elevation, the latter later and of less extent than the former, whereas, on the George shore, the proportions are reversed. Among the evidences of depression are cited the rock-channels of Parahyba, now filled with mangrove swamps and mud, which have sunk at least 36 feet since the channels were cut, thus resembling the rock-channels of the Keurboom's River. Evidences of elevation occur in raised beaches in the Bay of Bahia, and at Ilheos, in the State of Bahia, there are as high as 24 feet.[1] In South Africa, there is the high-level plateau, 600-800 feet above sea-level; but besides this, in Bredasdorp, Mr. Rogers and myself found a well-marked beach, with large boulders, about 100 feet above sea-level, in the sand-dunes, above the roof of the cave at Cape Infanta.

This last fact proves beyond doubt that the sand-rock has at one time been sunk beneath the tide level to 100 feet, and the evidences for a large mass of it still beneath the water on the George coast are sufficiently satisfactory, so that the theory of the sand rock being ordinary beach-sand hardened *in situ* must be ruled out. We have then proof of a see-saw motion in the rising and falling of the land, the former largely prevailing.

Of the earlier temporary depressions, there are no traces left; but among the stages of elevation we have the 1,500 ft. plateau about De Vlugt; the 700 ft. plateau forming the present coast ledge; the 100 ft. beach at Bredasdorp; and the 10 ft. beach at Port Elizabeth. Below sea-level, we have the Keurboom's River rock-channel, 100 ft. below, and the plateau whose edge is

[1] J. C. Branner, Bull. Mus. Comp. Zoo. Cambridge, Mass., 1904.

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known as the Agulhas Bank, 500 ft. below tide-level. We can put the facts thus:—

There has been an elevation from some unknown depth to the edge of the Agulhas Bank	x
From the Agulhas Bank to Keurboom's River rock-channel	400 ft.
From this to Port Elizabeth raised beach	110 ft.
From this to Bredasdorp raised beach	90 ft.
From this to Uplands Plateau	600 ft.
From this to the De Vlugt Plateau	900 ft.
Total	x + 2,000 ft.

There has been a depression of the Bredasdorp raised beach to the Port Elizabeth raised beach	90 ft.
From this to the Keurboom's R. rock-channel ...	110 ft.
From this to the Agulhas Bank	400 ft.
From this to an unknown level	x
Total...	x + 600 ft.

As regards the 700 ft. Uplands coastal plateau, I have again seen reason to doubt the conclusion that Mr. Rogers and myself came to in reference to its being a peneplain or base-level of river erosion, and not a plain of marine denudation. The presence of Chara seeds in the capping quartzite in Komgha seemed to settle that the deposits found in the plateau were fresh water, but since then, Anderson has described a deposit containing Chara seeds on the shores of Lake Sibayi, in Zululand,[1] a fresh water lagoon in a low coast plain; seeing that there has been recent elevation in South Africa, it seems very probable that this Zululand plain was one of marine denudation. At Port Elizabeth, the deposits on the raised plateau are manifestly marine. Why I am now led to favour the marine origin of the Uplands Plateau is because it is so narrow (see Fig. 12, p. 70), and it seems impossible that rivers from the steep mountains behind could, in the short course which the width of the plain allowed, come to such a quiet flowing stage that they were enabled to cut sideways and reduce the once rugged country to a more or less dead-level.

In Europe these continental ledges have been studied very thoroughly recently by Professor Hull, and, in his opinion, the submarine plateau that borders the northern continent was formed by wave action, on land emerging from the ocean. Notwithstanding its marine origin, this plateau between the Eng-

[1] 2nd Rept. Geol. Survey of Natal, London, 1904, p. 51.

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lish Channel and the Straits of Gibraltar carries gravel, sand, clay, and occasional mollusc remains. Similarly our 700 ft. plateau carries gravel, sand, and clay, now consolidated by surface hardening by infiltration of iron compounds and silica, and at Port Elizabeth carries wide areas of shells in a sub-fossil condition. If such high authorities as Profs. Hull and J. Giekie are content to regard the European continental ledge as a plain of marine erosion after the most exhaustive researches, it seems to me that when we have identical features reproduced in South Africa, we are justified in coming to similar conclusions. In Europe, the continental plateau is submerged 100 fathoms below; in South Africa, it is elevated 100 fathoms above sea-level. In the plateau whose margin is known as the Agulhas Bank, however, we have a ledge exactly resembling the European continental ledge; it is submerged 90 fathoms, and the dredgings of the S.S. Pieter Faure have brought to light boulders and sand 40 miles out to sea.

Off our coast we have, then, a succession of terraces, one of which is deeply submerged, and two others, taking the more pronounced ones only, elevated 700 and 1,500 feet. In the European ledge off Cape St. Vincent there is a similar succession of terraces, the lowermost going down to 200 fathoms, a condition which would be reproduced on our coast if the sea stood at the level of the Uplands Plateau. Between Morocco and the Canaries there is a broad terrace submerged between 600 and 1,000 fathoms, the whole movement in Europe pointing to a vertical displacement of over 8,000 feet. What I wish to emphasise is that it is proved in Europe that a succession of surf-cut terraces lie beneath the waters of the ocean; off our coast the same ledges exist, but most of them are above the level of the sea. Europe, then, is at the end of a long period of sinking; South Africa is towards the end of an equally long, if not longer, period of elevation. In Europe we notice the rivers running in wide channels, and the topography of the land generally is intensely dissected; in South Africa the rivers run in deep gorges, and the land surface is flat and plateau-like.

The deposits on these plains along the coast which we are describing are not characteristic, like those on the Swellendam Ruggens; the rock surface seems to have been bare, and to have gathered soil by disintegration, with the addition of blown sand. Over the greater portion of the plateau, whether cut in granite, Bokkeveld beds or Table Mountain sandstone, the soil is sour, and carries a layer of either "pot-clay" or ironstone gravel as a sub-soil.

The pot-clay is in most cases a fine, white, quartz meal, without any kaolin; it balls and moulds when wet exactly like a clay, but when it is attempted to burn it into bricks, the result is that the coherence of the particles is destroyed and the mass reverts to its true nature as a sand. Sometimes, however, where

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this "pot-clay" forms on granite or slate beds, then it does become a true clay—for instance, at Storm's River village—and under these circumstances it can be used for brick-making and even pottery.

The ironstone gravel is a peculiar deposit beneath the soil, forming a sub-soil between the rock and the true soil. It is formed by the coating of sand-grains by hydrated oxides of iron; sometimes this process results in the sand grains becoming separated, and a mass of rounded, shot-like particles are produced, usually of small size, and never larger than a walnut. At other times the whole becomes a sandy ironstone, all the material running together to form a continuous bank. Under the moist earth it is usually friable, but where the covering is removed, and it lies exposed to the surface, it becomes very hard, and forms a sheet of ferruginous rock, resembling a lava-flow;

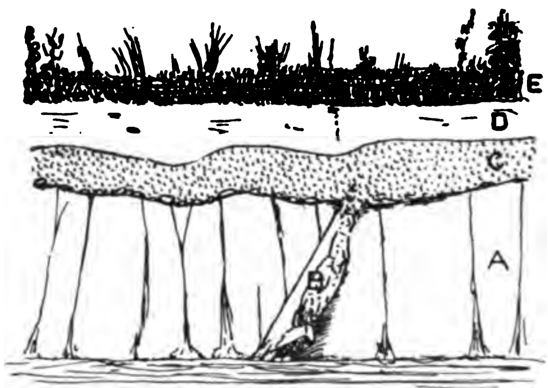

FIG. 15.—Section in railway cutting south of George Town, showing the formation of sour soil. A, Decomposed granite; B, Quartz-vein; C, Iron-stone gravel; D, Grey soil; E, Humus.

it then breaks up into quadrangular slabs by the slow desiccation and consequent shrinking. The depth of the deposit varies, but is seldom over two feet thick. In a wide sense of the term it might be called laterite, but there are little or no aluminous compounds where it forms on the Table Mountain sandstone or even on the George granite. It has formed by the rock disintegrating *in situ*, but owing to the want of drainage in the soil, the iron in solution in the water, which comes to rest above the hard rock, is deposited far in excess of the original constituents of disintegration (Fig. 15).

Where the ironstone is present the soil is sour, yet if the surface be tilled so that the air can penetrate, the sourness gradually disappears. On the granite, where the soil is thus rendered fertile, it answers admirably for orchards; the roots of the trees seem to penetrate beneath the ironstone layer, and to tap the

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loose granite beneath. If it were possible in practice to extract the granite and strew it on the surface, as is done in England, where soil on the Chalk becomes sour, and pits are dug, and the sub-soil brought on to the ground, the George sour-flats might be made very fertile.

Sour soil on Table Mountain sandstone cannot yield good results without artificially bringing on to it the necessary plant foods which are absent entirely from the disintegrated sandstone, the chief want being lime; round Knysna village the calcareous sea-sand to a certain extent near the coast brings this constituent naturally, and makes the soil sweet, but to the east along the flats before one reaches the Blue Krantz River, and beyond, in the Zitzikamma, there is no material near at hand which could supply the want, unless it is the calcareous shale in the Bokkeveld beds. It would be interesting and useful if this point could be cleared up; the shales would have to be analysed till one was found sufficiently rich in lime to be worth quarrying, and at the same time a suitable spot would have to be found where they could be advantageously brought up to the high-level plateau. As far as I am able to judge, I would advise that the shales about the mouth of the Storm's River should be examined, as there is already a wire rope-way established for hauling heavy material half-way up the hill, and the slates are well-exposed.

The blown sand commences again on the Rob-hoek,* where the grass begins to get mellow, and at Aasvogel Point and Zitzikamma Point, there are lofty dunes. Formerly these were covered with bush and the sand was prevented from scattering, but some 30 years ago, on the latter sand mountain, two bulls began fighting, and tore up the ground over a considerable area; the wind caught this bare patch in the bush, and gradually the loose sand spread, till to-day there are several miles of shifting sand where formerly there was excellent pasturage.

The soil on the Bokkeveld beds along the Keurboom's River is a lime soil, and very fertile; the steepness of the river banks makes much of this valley useless. The same soil is found in the slate outcrop that runs east from Storm's River.

There is also a third variety of soil besides the sour and the lime soil, namely, the brak soil; this is found in the estuaries of the Knysna, Bitou, and Groot Rivers, and is due to the accumulation of sediment in deep rock channels; it is also found along the Knysna lakes, but the calcareous sand makes it somewhat of a different character from the normal brak meadow-land in the open river estuaries. The brakness is quite different from the Karroo kind; it is caused by the common salt contained in the sea-water. Where the estuaries are cut in Uitenhage beds, as along the Knysna and Bitou Rivers, the gypsum

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* **Misspelt Roe-buck; the word means, Rob, a seal; and Hoek, corner.**

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derived from these deposits neutralises the salt by a chemical interaction of the salts:—

$$CaSO_4 + 2\,NaCl = Na_2SO_4 + CaCl_2$$

The calcium chloride then combines with carbonic acid present in the humus, and liberates hydrochloric acid, forming lime. The process resulting in the change of the harmful common salt into the harmless sulphate, and the acid, being converted into a liquid form, easily drains away in the porous soil.

APPENDIX.

The Mineral Deposits of Knysna.

The mineral deposits in Knysna consist of the following:—In the Table Mountain series, gold, galena, and zinc-blende; and in the Bokkeveld series, pyrites, more or less cupriferous.

There is one fact which the whole of this investigation proved, that must be considered in dealing with this question, and that is, that the country rock of the known deposits of minerals was laid down after the first mineralisation of the strata had taken place; in other words, that what minerals these Silurian and Devonian rocks do contain has been derived from the disintegration of beds containing those minerals, and that they are not themselves traversed by veins filled in with minerals derived directly from deep-seated sources.

Where was the country rock derived from? There is little doubt now that the sediments were derived from a northern continent, the Table Mountain sandstone being formed close off-shore, and the slates farther out to sea. The relative positions of deposition, or the prevalence of off-shore and deep-sea conditions, was not simultaneous, but the one succeeded the other owing to the sea-bottom sinking.

From what we know of this northern continent, which existed in these Siluro-Devonian times, from an examination of the remains of it where it emerges from beneath the later covering of sediments in Namaqualand, Prieska, and the Transvaal, the rocks of which it is comprised contained many richly mineralised areas, the Rand banket and the Namaqualand copper ores being two instances.

The rivers flowing from this land would carry down such minerals that were exposed by the slow wasting of the land, and the heavier, less soluble ones would come to rest in the sandy off-shore deposits, while the muds and clays further from the land would receive the lighter and more soluble ones. I do not wish to insist on this gravity sifting, but it is certainly the case that gold and lead occur in the Table Mountain sandstone and the copper ores, which are very soluble, in the hardened mud now turned into the Bokkeveld clay-slates.

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The floor of Pre-Cape rocks in which these sediments were laid do not in this district show any sign of mineral wealth, so that we must look far afield for the origin of this mineral occurrence. The absence of metalliferous quartz veins in the Pre-Cape rocks is another link in the argument to prove that the metalliferous veins in the adjoining Cape formation have not derived their contents from a deep-seated source.

In the Table Mountain sandstone the major bulk, and it was very small in itself, of the gold, lead, and zinc, seems to have come to rest in a beach or gravel deposit that occurred near the end of the deposition of the series; this is now represented by a banket or quartz-pebble conglomerate, and occupies a position which elsewhere the shale-band occurs, and where also the Clanwilliam glacial conglomerate comes in. No official assay of this rock has been made, but I have heard it stated that it carries 2 dwt. per ton. In the Bokkeveld slates the copper and iron in solution became precipitated in among the layers of mud from which it slowly crystallised out, sometimes in pyritous layers, sometimes in cubes of pyrites. It seems rather far fetched to bring in the action of bacteria in this connection, but it has been definitely proved in the Black Sea that these minute organisms exist in the waters, and have the power of secreting pure sulphur; when they die the sulphur, minutely divided, combines with the iron and copper in solution in the water, and these are precipitated as sulphides in the mud collecting on the floor of the lake.

This, then, has been the first stage in the mineralisation of these beds, the ores are distributed in among the sediments.

The second stage occurred when the crushing of the beds, after being laid down, took place. As we have previously seen, this thrust was brought up against the inland sides of the great granite bosses, and where these end, there was a tendency to flow round the termination; in other words, there was produced a tension in the neighbourhood of the end of the granite, whereas the rest of the country rock was under pressure. The tension was relieved by the beds cracking. Into these fissures water, containing silica and metallic substances in solution, gradually leaked. It has been proved experimentally that under great pressure even at low temperatures many substances pass naturally into solution, which under atmospheric pressure are almost entirely insoluble. At the same time, substances like gold and silica become soluble when there are minute traces of certain salts in the water; free chlorine and ferric sulphate in solution act upon gold, and salts of the alkalies on silica. Both these causes were present to abstract the quartz and metallic substances from the banket and sandstone beds, and the liquid naturally passed from areas of pressure to the open cracks, and in that way slowly filled these up with the re-deposition of the dissolved constituents. According to the ratio between the

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dissolvent salts, much or little gold accompanied a given quantity of quartz in its deposition in the fissures, so that in some instances quite a rich reef became built up, and in others, only barren reefs. From a study of the actual reefs in the Millwood area, it is seen that besides the substances like gold, galena, and blende, with the silica, that are deposited from water, there must have been in the initial filling of the fissures a good deal of material carried mechanically into them, for the quartz reefs are often veined and coated with a glistening, slaty material. In the Bokkeveld area, however, the quartz reefs are massive, white quartz, without any foreign admixture, except the copper and iron pyrites.

In the Table Mountain sandstone, about Millwood the reefs are much divided and splintery, as if the formation of the fissures were due to a tearing action; we may, perhaps, refer this to the varying tensile strengths of the sandstone beds, which have in that respect a more diverse constitution than the slates and calcareous or argillaceous sandstones of the Bokkeveld series. In the latter the fissures are clean cut, and the white quartz fills in the whole from wall to wall.

As regards the vertical extent of these reefs, we find them at the following altitudes above sea level:—

Hickfang's mountain reef...	2,600 feet.
Temperance	1,860 „
Central...	1,600 „
Bendigo...	1,560 „
Bella	1,360 „
Milne...	1,310 „
Oudtshoorn	1,210 „ *

These are all in Table Mountain sandstone; in the Bokkeveld beds we find them in the Little Homtini at a couple of hundred feet above sea level. Considering that the present surface of the land is not an original one, but has been formed by the removal of immense quantities of material by denudation, the original upward extent of the reefs above sea level may be safely stated to have been twice that which they now attain, namely, 5,000 feet, and since the reefs that are seen near sea level along the Little Homtini show every sign of continuing indefinitely downwards, the reefs at Millwood may be expected to reach at least a thousand feet below sea level. The question whether any particular reef will reach down to the extreme depth is only to be found by actual working, and a prospector on the spot should be able to see whether the reef shows signs of pinching out, or whether it is likely to last with depth. Even should the reef pinch out with depth, I am inclined to think that it will come in again lower down, as these reefs are the results of shells

* I am indebted to Mr. P. Fletcher's Report, G. 17—'91, for these figures.

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of tension, which occur at given distances from the granite; the direction of the reefs is determined by the strength of the rock, but their extent is determined by depth to which the tearing force has acted.

In regard to the gold content of the reefs,—we can confine ourselves to this particular ore as the arguments for the galena and blende would be the same,—we have two factors to consider, surface enrichment and permanent content. The latter is determined by the circulation of water bearing gold in solution, and this again is determined by the depth of the strata containing gold, which we have reason to believe are the banket reefs. The banket dips steeply south just below the junction of the Millwood creek and the Homtini, and comes up again along the Homtini on the south side of the Bokkeveld inlier; it must, therefore, pass beneath the Bokkeveld beds, and thus attain a depth of a couple of thousand feet at least beneath sea level. Circulation of water through the substance of the rocks will go on wherever there is pressure in one place and an open space in another, and, therefore, will be active along the whole length of the quartz reefs from top to bottom. As the solution of the gold depends partly on pressure it is reasonable to suppose that the gold content of the water will be larger the deeper it circulates, and as a result the gold reefs will be richer at greater depths than they are found to be at the present surface. We must remember in this connection that we are dealing with infilled veins, and not with a stratified ore body like the banket; in the latter case one would expect the gold content to be independent of depth, while in the former case the solvent power of water under increased pressure has full play to exert its influence.

The surface enrichment of quartz veins may be considered as part of the third stage; the second stage in the mineralisation of the rocks being the leaching out of the gold and deposition of that mineral with quartz from solution in suitable crevices.

As the surface of the ground weathers away the reefs containing gold are exposed, and themselves slowly crumble away. The gold in the disintegrated portions being very heavy, tends to remain where it is, but the surface water is not pure water, but contains certain salts which act strongly upon gold.

The first and most natural solvent of gold that might occur is free chlorine. The water of Millwood is strongly tinged reddish brown from washing through the rank, marsh soil, and it is known that plant roots elaborate to a certain extent hydrochloric acid; the latter is not itself a solvent of gold, but it is quite possible that to a certain extent free chlorine may exist with the acid, and in that case a strong solvent solution would result.

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Other solvents are sodium and potassium chloride,[1] sodium silicate,[2] sodium sulphide, sodium sulphydrate, and sodium carbonate saturated with sulphydric acid.[3] Doelter has found that gold is soluble in sodium carbonate and sodium silicate heated in iron tubes to 200° to 250° C.; when the experiment had continued for 47 days, the tubes were opened and small aggregations of gold crystals were found imbedded in a mass of crystalline and globular quartz.[4]

Recently Atkin has suggested that the more probable natural solvent of gold is ferric sulphate, which, on reduction to ferrous sulphate, immediately precipitates the gold.[5]

At Millwood the supply of this ferric salt would be far in excess of all the others put together, since the blue colour of the Table Mountain sandstone, as it exists in the unweathered state, is due to sulphides of iron, whereas sodium compounds are absent from the formation traversed by the streams. There may, of course, be other solvents which can act when years are allowed for the process, and when tons of material are exposed, which cannot be examined in the test tubes of the laboratory, but as ferric sulphate can dissolve the gold and is present in the waters, it does not seem that one need seek further for a solvent salt.

In ordinary storms the water falls heavily upon the surface of the ground and a certain amount of gold might be carried a short way mechanically, but the major portion of the water would flow away so rapidly that it would not have time to absorb salts from solution. When the rain had passed, then the residual portion of the water that had sunk into the ground would begin to percolate, and as the time from the original precipitation became longer and longer, the passage of the water would become slower and slower. In the later stages of drought the water would become comparatively strongly charged with the ferric sulphate. All cracks, crannies, and hollows of whatever nature would now draw in this water, which, having passed slowly over the quartz reefs, will have had time to dissolve a certain amount of gold; especially favoured parts like the joints in the sandstone would hold this water, and on evaporation the gold would be precipitated. The quartz reefs themselves, where they have become broken up on the surface and have had part of their substance already washed away, would likewise be convenient places for this water to settle, and consequently the surface of the reefs would become re-charged with gold even on a more plentiful scale than originally.

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[1] Egleston, Trans. Am. Inst. Min. Eng., 1880, VIII., p. 455.
[2] Liversidge, Proc. R. Soc., N. S. Wales, XXVII., 1893, p. 303.
[3] Becker, Mon. U. S., Geol. Surv., XIII., 1888, p. 433.
[4] Chemische Mineralogie, Leipzig, 1890.
[5] The original papers of Le Conte and Wurtz are not available; they are quoted by Mr. Atkin, Q.J.G.S., 1904, LX., p. 390.

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It is an interesting speculation whether the two forms of nuggets, the rounded and the sharp-edged, may not be caused in the one case by sudden precipitation, due to the reduction of the ferric salt to the ferrous, and in the other by the slower process of evaporation.

I do not wish to maintain that no gold is carried down mechanically into the stream beds, but what I think the facts point to is that the larger proportion of nuggets found are derived from chemical solution and precipitation.

The following are the chief factors in arriving at this conclusion:—

1. The nuggets of gold are found in between joints and under ledges of rock associated with fine mud; if they had been carried into these positions mechanically, it is hard to explain their presence when the matrix they lie in is of so much lighter material.

2. The nuggets are often of large size, and it is never found that the gold in the quartz veins is in nugget form.

3. The nuggets are of very varying appearance, some being apparently water-worn and rolled, others are quite fresh, with sharp edges, and cannot have travelled any distance from their original position.

4. Gravelly hollows in the stream bed, after being worked out, become after a few seasons filled again with gold nuggets, though the reefs about the stream banks are known not to contain nuggets.

5. The theory of chemical solution and precipitation adequately explains all known facts.

As regards the ores associated with the gold, namely, blende and galena, it very frequently happens that these two minerals accompany the precious metal; for instance, in Merionethshire, in Wales, gold quartz veins, sometimes with calcite, carry iron pyrites, copper-pyrites, zinc-blende, and galena; in Chota Nagpur, gold quartz carries iron pyrites, arsenical pyrites, and galena; Western Australia gold quartz carries iron, copper and arsenical pyrites and galena; California gold quartz carries iron pyrites, blende, galena, arsenical and magnetic pyrites, copper pyrites, and cinnabar; in Takon, Alaska, gold quartz carries ores of silver, lead, copper, and zinc: in Andacollo, Chili, gold quartz carries iron, copper, and arsenical pyrites, blende, stibnite, and galena. Instances might be multiplied indefinitely, but the frequent association of these three minerals, gold, galena, and blende, is sufficiently indicated in the above list; it would be a work of great interest if the full mineralogical content of the Millwood reefs could be worked out.

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Most of what I have said relative to the passage of ores from the surrounding rocks into fissures which are filled with quartz contemporaneously with the mineral deposition, in reference to the Table Mountain sandstone region, applies to the Bokkeveld area, only here the ores, copper and iron pyrites, are not massed in a particular band, but were disseminated originally throughout the series. With these pyrites reefs, however, there is no subsequent enrichment in the sense of the third stage of the process of gold formation.

In conclusion, the examination of the Millwood area has led me to trace the original seat of the gold to the banket beds; the precious mineral is leached out of this and deposited in quartz veins. These latter are sometimes extremely rich on the surface, but are poor in the bulk.* All estimates of the value of these reefs must, however, be taken with great caution, as no work has been done on them systematically; the failure of most of the companies hitherto working in the area has been due to reckless mismanagement, and in addition, when at last legitimate work was commenced, the Witwatersrand banket was discovered, and all available capital was invested in the Transvaal. There is reason to believe that the reefs will improve in value with depth. Although the Millwood reefs are low grade, as far as I was able to judge, they ought to repay working under competent management, owing to their favourable situation in regard to nearness to the sea-board and abundance of water and wood in the vicinity. If one-hundredth part of the money which has been squandered on these fields had been employed for the set purpose of proving or disproving the payable nature of any one of the reefs under experienced guidance, I have no doubt that a large industry would have been established there for a long time now, but with the hundreds of thousands that have been spent there, we are still ignorant as to whether any single reef will repay working or not. The recovery of the alluvial gold spread out on the gravels on the Poverty Flats and in the estuaries of the Knysna and Homtini (Gouwkamma) Rivers should be worth attempting in view of the enormous quantity of country rock riddled with gold-bearing quartz-veins that has already been disintegrated and washed down from the Millwood area, it matters not in this respect whether the gold was carried mechanically or in chemical solution.

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* I was told that a trial crushing of the Oudtshoorn reef gave 2 dwt. over the plates, and 2 dwt. in the tailings, but there is no record of what was put into the battery, whether picked reef or reef and country rock together.

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Return of Gold Registered at Millwood.

	oz.	dwt.	grs.		oz.	dwt.	grs.
1887	335	11	21	1898	113	9	6
1888	448	13	11	1899	130	16	16
1889	113	17	14	1900	125	18	21
1890	300	16	5	1901	78	0	0
1891	406	8	5	1902	25	18	12
1892	442	19	9	1903	12	2	4
1893	244	4	12	1904	36	11	15
1894	166	13	4	1905	29	6	16
1895	22	—	—	(up to March).*			
1896	94	—	—				
1897	43	—	—				

*** From 1887 to 1894 the returns are published in the reports of the Inspector of Mines; from 1898 to 1900 in the Reports of the Conservator of Forests; the other figures I obtained from the Agricultural Department through the courtesy of Mr. B. McMillan.**

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GEOLOGICAL SURVEY

OF

GLEN GREY, AND PARTS OF QUEENSTOWN AND WODEHOUSE, INCLUDING THE INDWE AREA.

BY

ALEX. L. DU TOIT.

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THE GEOLOGICAL SURVEY OF

GLEN GREY, AND PARTS OF QUEENSTOWN AND WODEHOUSE,

INCLUDING THE INDWE AREA.

I. INTRODUCTORY.

The area surveyed is approximately 2,400 square miles in extent, and consists of the southern portion of Wodehouse (all to the south of the main watershed), the whole of Glen Grey, and the greater portion of Queenstown, the limit being the Zwart Kei River, and thence across to St. Marks.

Special attention was given to the Indwe and Sterkstroom areas, because of the economic importance of the coal deposits and on account of the geological difficulties encountered.

The divisional map of Glen Grey, on the large scale of 400 Cape roods to the inch, proved satisfactory for the work; that of Wodehouse, on half the above scale, was so untrustworthy that it had to be entirely redrawn; while in the case of the Indwe area a special large scale map was constructed in the field.

The area examined is drained entirely by rivers flowing into the Indian Ocean:—the Indwe, Cacadu, White Kei, Klaas Smit's, and Zwart Kei Rivers, all tributaries of the Great Kei.

On the north is the watershed of the Stormberg, forming a fine escarpment near Sterkstroom. South of Dordrecht the divide is by no means pronounced, but north of Indwe the valley of the Doorn River is separated from that of the Waschbank by a lofty spur of the Drakensberg, which attains an altitude of 6,700 feet above sea-level.

The country is very mountainous in the northern portion of Glen Grey and to the east of the Indwe River. Along the Queenstown boundary, east of the railway from Sterkstroom to Lesseyton, the high ground culminates in the rugged dolerite mass of the Andriesberg. An extension of this ridge is the dolerite-crowned mountain Hangklip (6,700 feet), overlooking Queenstown. In the southern portions of Queenstown and Glen Grey, prominent ridges of dolerite traverse the country in various directions, but westwards, and away into Tarka, we find the typical Karroo scenery, wide flats with isolated ridges and peaks, often table-topped and crowned with dolerite. The whole area is thickly covered with grass in the summer time; towards the south and south-east there is an abundance of mimosas and aloes.

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The Formations.—The strata met with belong either to the Burghersdorp (Upper Beaufort) or to the Molteno Beds; the higher strata, Red beds and Cave sandstone, are of limited extent in this area. The beds lie nearly horizontally, but there is a general slight northerly dip. Dolerite intrusions penetrating the sedimentary rocks occur on a very large scale, and have produced great dislocations and disturbance in the strata, in fact, almost invariably the beds on opposite sides of a dolerite sheet are displaced.

II. The Burghersdorp Beds.

Rocks belonging to this sub-division of the Beaufort series form the whole of the southern and south-western portions of the area surveyed. The maximum thickness of this formation as yet mapped is between 2,000 and 2,500 feet, the lowest strata appearing along the valley of the Zwart Kei, between Kamastone and Tylden. Further to the south-west, the general surface of the country rises once more to form the Great Winterberg Range, and it is probable that some of the higher strata re-appear in that direction.

Throughout this great thickness of material, the formation maintains a wonderful lithological uniformity, though the strata at Tylden are slightly different in character, indicating that the base of this sub-division of the Beaufort series is being approached. The Burghersdorp beds in this area have characters identical with those of the beds of the same formation in Aliwal North, described in the last Annual Report (pp. 77-82).

In the latter area only a small thickness of strata was exposed, chiefly the somewhat variable zone of transition into the Molteno beds. In this part of the Colony it was found that after a distance of from 100 to 200 feet below the base of the overlying formation, the strata become perfectly regular and uniform, so that, from the lithological characters alone, it is impossible to determine the actual stratigraphical horizon of any particular stratum.

While the Molteno Beds constitute a formation which is essentially arenaceous, the Burghersdorp Beds belong to one which is practically argillaceous. The sandstones are usually of no great thickness, and are light coloured, fine grained, and felspathic; often the quartz grains show secondary enlargement and crystal faces, so that the sandstone has a tendency to sparkle in sunlight. Some of the thin ribs weather into rounded lumps, like the fine-grained hard sandstone layers around Beaufort West.

The softer rocks often form layers over a hundred feet thick, and consist of mudstones, with thin bands of friable sandstone of deep reddish, violet, or purple colour, commonly alternating with greenish varieties. Mottling is very frequent. Calcareous

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bands are not uncommon, and calcareous matter may be present in sufficient quantity in some of the mudstones to justify the name of "marls" being applied to them.

The water derived from rivers flowing over, or wells sunk in, the Burghersdorp beds is always hard, and in some places distinctly brackish. One marked example is a small stream in Glen Grey, crossed by the road from Driver's Drift to Bolotwa. Salt water was obtained in one of the boreholes put down in the village of Lady Frere.

Fossils occur in the Burghersdorp beds at a number of points. Plant remains have only been found in the sandstones, and are therefore rather badly preserved; bones occur both in the sandstones and the mudstones.

Although the distribution of the reptiles is not yet very well known, it appears that the upper portion is characterised by the presence of theriodonts, *e.g.*, *Gomphognathus* and *Cynognathus*, while from the lower *Procolophon* has been obtained.

At Indwe.—Commencing with the description of the Burghersdorp beds at Indwe, we find that along the Doorn River there is usually a great thickness of alluvium, and that the purple clays and shales are exposed only at a few points.

Deep dongas or ditches are being cut in this alluvium, and in this connection, attention may be drawn to an article* by Mr. G. E. Dugmore, M.L.A., on the erosion in this locality. At only one point is the junction of the purple rocks with those of the Molteno beds seen, but from borehole records the boundary line on the map has been located.

The Doorn River flows through a narrow "poort," about three miles south of Indwe. This is an excellent site for a dam, as was long ago pointed out by Mr. T. Bain (**13,** 18), and it is to be hoped that such a scheme may be carried out in the future, either by the Indwe Company or by the Town Council.

South of this stretches a considerable flat, over which outcrops of rock are infrequent. On the banks of the Doorn River, at the drift on the road from Indwe to Lady Frere, thin sandstones, with dark mudstones and shales, occur, including one reddish band of no great thickness. Some of the mudstones are crowded with small irregular dark nodules, which are hollow and filled with variously-coloured ochres. There is a marked local unconformity here, and in one place a bed of sandstone, for a distance of several hundred feet, rests horizontally upon the eroded edges of strata, dipping at an angle of about fifteen degrees.

These beds may be placed at the extreme base of the Stormberg series, for farther to the south and south-west the typical purple sandstones are well exposed; on farm, No. 6B, Block 3, a borehole penetrated about 100 feet of the latter without encountering any sandstone.

* Agricultural Journal of the Cape of Good Hope, March, 1905, p. 375.

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South of "Trennery's" (Indwe Poort), the Burghersdorp beds form a wide grassy flat, divided into two portions by the low dolerite ridge which constitutes the boundary between the Divisions of Wodehouse and Glen Grey. South of this extensive fertile flat the ground rises again, but the sedimentary rocks are to a great extent altered by dolerite.

In Glen Grey.—The Bengu basin is hemmed in by smooth dolerite hills, and all the drainage is directed eastwards into the Indwe River. Close to the trading station of Bengu there is a peculiar outcrop of white-weathering shales, and soft, slightly-spotted sandstones, reminding one very much of the "white band" of the Dwyka formation. These white or pale leaden-grey beds appear to pass laterally into rocks with a purplish tint; nowhere else was anything similar noticed.

The town of Lady Frere is situated at an altitude of about 3,400 feet above sea-level, in a basin-shaped area on the left bank of the Cacadu River. On the north-east rises the great mass of the Donga mountain (5,800 feet), while to the north-west is Mount Arthur (6,070 feet), both of which elevations turn precipitous faces towards Lady Frere.

The Donga Mountain forms a vast amphitheatre, the edge of the cliff face being formed by the Indwe sandstone, overhanging in many places; at one point, there is an immense cave.

From Lady Frere upwards there is exposed a vertical thickness ot 1,400 feet, or allowing for dip, about 1,600 feet of Burghersdorp beds. The strong contrast between this formation, with its thin sandstone layers and thick interbedded purple mudstones, and the massive sandstones of the Molteno series, is never better seen than on the eastern extremity of the amphitheatre. The Molteno beds form a precipitous face of almost solid sandstone, about 1,000 feet high. Huge masses of sandstone strew the base of the mountains, among which blocks of the coarse pebbly Indwe sandstone are conspicuous. Very noticeable, too, are the number of quartzite boulders which have weathered out of the Molteno sandstones.

The Donga Mountain is merely a shell of sedimentary material, the core, of dolerite, being formed by a highly-inclined sheet, which is exposed in the various kloofs and also on the east and west. The purple mudstones near the contact with the dolerite have for a considerable distance from the junction been altered to hard and splintery buff or terra-cotta coloured rocks, with the development of a rude columnar structure.

A rather thick sandstone caps several extensive plateaux around Lady Frere. This sandstone is light bluish-green when fresh, but weathers to a yellowish brown colour. It must be fully 60 feet thick, and has been extensively quarried for building stone. From it were obtained badly preserved fronds of *glossopteris* and striated and *lepidodendroid* stems; also two large fronds of a plant that has not yet been identified.

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The thick purple shales and mudstones often include hard greenish-grey sandstone ribs, from an inch up to a few feet in thickness. Purple sandstones are not very common, and are in thin bands. Reddish limestones are rare, but there are abundant light-coloured calcareous concretions of very irregular shape, while small septarian nodules are frequent.

From Lady Frere a quantity of reptilian remains, principally those of theriodonts, were obtained by Sir Bisset Berry, Mr. T. Bain, and Prof. Seeley, the specimens being described by the latter†:—

Gomphognathus polyphagus.
Cynognathus Berryi.
Cynognathus crateronotus.
Trirachodon Berryi.
Tribolodon frerensis.
Also an *anomodont* carpus.

A large number of boreholes have been put down within the town of Lady Frere, all of which have struck water at a moderate, though varying depth. Some of the boreholes give off odourless inflammable gas, probably "marsh-gas." One of the wells evolved a large quantity, but the supply is gradually diminishing. The gas is undoubtedly derived from a certain horizon in the purple mudstones, and not from the base of the alluvium, which is here up to 30 feet in depth.

Burghersdorp beds crop out on the low ground in the wards of 'Mkapusi, Buffeldoorns, and Vaalbank, in the north of Glen Grey. This large basin-shaped area is almost entirely surrounded by dolerite ridges, except to the north of Kapusi Mountain, where an escarpment is formed by Molteno beds. Alluvium covers a large portion of the floor of this basin; at Buffeldoorns trading station the White Kei has cut its way through about 25 feet of sand and gravels, while numerous dongas or ditches are in the course of formation in the neighbourhood.

To the north, north-west, and west the strata have been faulted down, so that the rocks exposed in the gorges of the Birds' and Buffeldoorn's Rivers, which rise in Wodehouse, and in Zwart Water, belong to the Stormberg series.

In the Qoqodala basin a sheet of dolerite exists just below the surface, and in consequence, there are everywhere patches of highly indurated and often columnar and prismatic sandstones and mudstones. The latter have been altered to a blue-black flinty material, chips and flakes of which strew the ground in considerable quantity.

The sides of this basin are formed by dolerite, and the intrusion extends eastwards into the ward of Agnes.

† H. G. Seeley, Phil. Trans. Roy. Soc. London, Vol. 186, part IX, sects. 4 and 5, 1895.

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South of Driver's Drift, along the banks of the White Kei, there is an abundance of flinty gravels, the material having been derived from the wards of Qoqodala, Agnes, and Nonesi. The main road from Driver's Drift to Queenstown crosses Nonesi's Nek, the rise being a little over a thousand feet; very fine sections are exposed along the road cuttings (see also Molyneux's description, **5**, 25). About four miles due east of Driver's Drift some reptilian remains were obtained, embedded in nodules of hard calcareous sandstone.

These include the posterior portion of a skull of *Gomphognathus polyphagus*, Seeley, which unfortunately wants the snout; and a portion of a reptilian occiput, possibly anomodont.

Along the White Kei, the shales and mudstones have a tint approaching violet, rather than purple. Bands of whitish or very pale blue arenaceous mudstone are frequent, also greenish shales and mudstones.

In the wards of Lante, Mbinzana, Bolotwa, and Macibeni,§ the Burghersdorp beds maintain their normal characters. At St. Marks (2,675 feet) and Tylden (2,890 feet), where the lowest beds yet examined crop out, there are differences. The sandstones are thicker and more abundant, and are often of a pink or lilac tint; shales and mudstones are not well exposed. Records of boreholes in the adjoining division of Cathcart, and in Queenstown, south of the Zwart Kei, show that the ratio of the proportion of sandstone to shale increases continually as the strata are followed towards the south.

In Queenstown.—The strata lie in an almost horizontal position around Tylden, and close to Whittlesea, but Dunn (**2**, 18) states that between the latter village and the Katberg the beds dip towards the south. It is therefore very probable, in view of the changes noted above, that the formation as a whole becomes more arenaceous towards the south. The area southwest of Kamastone has not yet been surveyed, but Stow (**1**, 526) has given a good description of the rocks around Tafelberg. The fossils from this locality include the theriodont *Galesaurus planiceps* (*Nythosaurus larvatus*, Owen),* and the labyrinthodonts *Micropholis stowii*, Huxley,† and *Micropholis granulata* (*Petrophryne granulata*, Owen)‡; while from the farm Donnybrook, a little to the south of Tafelberg, come numerous specimens of *Procolophon trigoniceps*,** Owen, and also the skull of a lizard *Paliguana Whitei*, Broom.||

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§ It is important to note that there are two wards, one Macibeni and the other Macubeni, in the south-west and north-east corners respectively of Glen Grey.

* Cat. Foss. Rept. and Amphib. Brit. Museum. Part IV, p. 70, 1890.

† Quart. Journ. Geol. Soc. Vol. XV, p. 649, 1859.

‡ Cat. Foss. Rept. and Amphib. Brit. Museum. Part IV, p. 174, 1890.

** R. Broom. Records of the Albany Museum. Vol. I, no. 1, p. 9, 1903.

|| *Ibid*, p. 1.

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Between the Zwart Kei and Queenstown are several annular ridges of dolerite, with intervening grass-covered flats.

At Queenstown itself are a few thin beds of sandstone, which furnish a building-stone of excellent quality. The principal quarry is situated to the north of the town, just beyond the Hospital. The stratum worked is a bed of very close-grained sandstone, bluish-green in colour and brownish-yellow when weathered. False-bedding is not uncommon, and is often at a high angle.

The portion of rock removed does not exceed eight feet in thickness, and of this a considerable amount has to be rejected owing to the inclusion of irregular patches and lenticles of green or blue shale, which may be present in such abundance as to produce a clay-pellet conglomerate. The clay-pellets are often of nearly uniform diameter, about the size of a pea or bean, and the peculiar fragmental rock produced may occur in layers of as much as three feet in thickness. Small lumps of calcareous material may be included, and on weathering, the rock becomes a porous mass. Small rolled fragments of bone are of frequent occurrence in these conglomerates. In the sandstones fragmental remains of plants occur very sparingly, and are nearly always portions of striated stems, probably those of *Schizoneura*. As a building material, the Queenstown stone is noted throughout the Colony, but there appears to be no reason why the sandstones of this formation in other parts of the Eastern Province should not be utilised too. Good stone has been obtained at Lady Frere, Driver's Drift, St. Marks, and many other places; it is therefore very likely that along the railway, at points between Rosmead and Steynsburg, excellent building stone can also be found.

The sandstone bed at the summit of Bowker's Kop, a small detached elevation overlooking Queenstown, is in places impregnated with the hydrated carbonates of copper. On the ridge forming the southern boundary of the Lesseyton Commonage, there is an outcrop of highly altered shale and sandstone adhering to the upper surface of a sheet of dolerite. The sedimentary and igneous rocks are firmly welded together, and development of epidote has taken place in the former, accompanied by minute quantities of pyrites, galena, and bornite.

About four miles north of Queenstown, at the head of a small valley, there is a prospecting shaft, which has been sunk on a narrow dyke or inclined sheet of dolerite. The strata in contact with the igneous rock are much brecciated, and in the middle of the dolerite itself, which is not more than two feet thick, there is a band of brecciated rock, cemented by quartz and calcite. Assays have not given encouraging results. Close by, on the ridge to the north-west, some fragments of bones were obtained by Mr. Martindale, of Queenstown, the horizon being about 1,000 feet below the base of the Molteno beds.

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These, Dr. Broom states, probably belong to a species of *Dicynodon*. It is of interest, because Dicynodon has been found in the same formation at Burghersdorp.*

In the Bongolo Valley, on the ascent of the Nek leading over into Qoqodala, there are fine sections of the Burghersdorp beds along the roadside.

At one point, where a considerable thickness of mottled purple mudstone is overlain by a solid bed of sandstone, the under surface of the latter is crossed with irregular ridges, while cracks are filled in with pink limestone. The basal portion of the sandstone is conglomeratic, with pellets of green and purple shale, limestone, and often abundant rolled fragments of reptilian bones. Evidently the surface of the mudstone represents an old mud-flat, on which pellets of clay and bones were rolled about before being covered up by coarse sediment. Stow (**1**, 544) mentions a peculiar "whirled sandstone" on the Bongolo Nek, but the only rock visible at the summit is a sheet of decomposed exfoliating dolerite, overlain by thick reddish-black soil.

North of Queenstown, the ridge constituting the divisional boundary is crowned with Molteno beds and overlying dolerite, outliers of the same occurring on the peaks Hangklip and Ben Hepburn.

Opposite the Zwart Water Location, the strata dip rapidly to the north, so that the Molteno beds are found in the valley just north of the police camp at Hill End. All the high ground westwards, to within less than a mile from the railway, is formed of rocks belonging to the Stormberg formation, the junction with the Burghersdorp beds on the south-east and south-west being concealed by dolerite intrusions.

From the railway, the surface of the ground slopes gradually westwards to the Klaas Smit's River, forming flats which stretch to the base of the Stormberg escarpment, a considerable distance away. This tract of flat ground is divided into two portions by a great double intrusion of dolerite on Doornhoek and Uitzigt, dipping south-eastwards, and giving rise to the towering masses of the Wildschuts Berg on the Tarka border.

Through this ridge the Klaas Smit's River has sawn a deep and narrow channel, nearly a mile in length. Surveys have shown that a retaining wall could be thrown across the stream in this "poort" at a comparatively low cost, and that the water impounded would cover many square miles of flat country to the north.

North-west of Putter's Kraal station the Tarka boundary, from the Stormberg escarpment as far as the main road from Sterkstroom to Tarkastad, is formed by a narrow spur of Molteno beds. The Burghersdorp beds cover wide flats, and extend up

* R. Broom. Annals of the S. Afr. Museum. Vcl. I, part 3, 1899, and Proc. Zool. Soc. London. Vol. II., p. 86, 1902.

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the Haasje's Kraal Spruit as far as the farm Wilge Kloof. To the north, along the foot of the Stormberg escarpment, as far as Bushman's Hoek, the purple mudstones and shales are fairly well exposed, and the base of the Molteno beds can generally be fixed to within about 50 feet. Especially fine sections are seen in the deep narrow kloofs at the head of the Buffels Kloof Spruit, a bird's-eye view of which is obtained during the descent by rail from Cyfergat to Sterkstroom.

III. The Molteno Beds.

Molteno beds cover almost the whole of the south of Wodehouse, and also small areas in the north of Queenstown and Glen Grey. There is a general rise of the strata towards the south-west, so that in the central and southern portions of the two latter Divisions outliers of Molteno beds cap the highest elevations only.

The formation is essentially arenaceous, more so in this area than in the country to the north; but this fact is not usually manifest, except from a study of boring records. However, at Lady Frere, as mentioned earlier in this report, and at Mount Arthur, Hangklip, Zwaart Water, Bushman's Hoek, and on the Tarka boundary, the great development of sandstone is very clearly seen.

The sub-divisions of the Molteno beds proposed in the Report on the Divisions of Elliot and Xalanga,* can, with slight modification, be adopted for the area west of the Indwe River also. The *Indwe sandstone* is the most important sub-division, and its boundary has been mapped throughout this area, but the higher members are not so easily recognised. The *Gubenxa sandstone* can, in a few places, be identified, but the Molteno beds are so often disturbed by dolerite intrusions and patches of the formation isolated, that it is often impossible to be certain about the higher horizons. The sub-divisions are as follows, using the same numbers as in the 1903 Report:—

- 9-6. White sandstones, with thick beds of pebbly and "glittering" sandstone, bands of dark mudstone and shale, and occasionally thin coals.
- 5. Coal horizon (Cala Pass, Tarka, etc.).
- 4. Soft fine-grained sandstones.
- 3. Indwe sandstone, coarse and pebbly, with ironstone nodule band.
- *2b*. Guba coal horizon.
- *2a*. Fine-grained bluish grey sandstone, about 80 feet thick.
- 2. Indwe coal horizon.
- 1. Fine grained grey felspathic sandstones, with thin beds of grey and buff shales and mudstones.

* Ann. Rept. Geol. Comm. for 1903, p.175.

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There is a general thickening of the Molteno formation towards the south and south-east. Thus the strata below the Indwe sandstone have a thickness of from 150 to 250 feet in Aliwal North, 450 to 500 feet at Sterkstroom and Indwe, 700 feet at Cala and at the head of the Guba River, and about 1,000 feet at Lady Frere. The total thickness of the formations varies in a similar manner, *e.g.*, 1,000 to 1,200 feet in the north, from 1,200-1,400 feet along the south of the Stormberg, and 1,900 feet in Elliot. Apparently the Red beds, and usually the Cave sandstone, vary similarly.

For convenience in description, the tract occupied by the Molteno beds will be divided into three sections:—(i.) the Indwe area (*e.g.*, that included in the map accompanying); (ii.) the area lying to the west and south-west of Dordrecht; and (iii.) the Sterkstroom area.

(1). *The Indwe Area.*

The Indwe centre is one of the most important of the coal-producing areas in the Cape Colony. Although the existence of the seam had been known for many years, and although the reports of various experts engaged by the Government had been very favourable, yet nothing was done until the Indwe Railway and Collieries Company constructed a line from Sterkstroom to Indwe. The township of Indwe sprang into existence, and although no more than twelve years old, is already larger than Dordrecht. The output of coal from the Indwe mines has been fairly constant, as will be seen from the following table*:—

1897	51,218	tons.
1898	107,497	"
1899	132,603	"
1900	129,009	"
1901	129,819	"
1902	116,154	"
1903	133,584	"
1904	108,021	"
1905	82,220	"

The area at present being mined, known as the "Camp," is roughly triangular in plan, with its apex directed to the south, each side having a length of about one and a half miles. This triangular area is crowned with the Indwe sandstone, and the coal crops out just below the escarpment bounding the plateau. There is a general dip of nearly two degrees to the north-north-east. The continuity of the seam along the hillside has been

* I must acknowledge my indebtedness to Messrs. G. Dugmore, M.L.A., and W. Whitaker, Directors of the Indwe Collieries, and to Mr. J. Colley, Mine Manager, for abundant information, and for permitting me to examine the plans and boring records.

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proved by a number of openings, but the coal is being worked from four drives only, *e.g.*, the Byrne mine (on the west), the Green mine (on the south), the Dugmore mine (on the east), and the Milner mine (between the last two, but closer to the latter). The old workings, known as the Spriggton mine, are in the very apex of the mining area, but this portion has all been worked out. There are a number of dolerite dykes crossing the field, which have to a considerable extent determined the area that can be worked from each of the four openings. In both the Byrne and Green mines the dip of the seam in the workings is away from the outcrop, and therefore the grade is adverse to haulage and drainage.

In the Dugmore mine, which has the largest output, there is a complete electrical haulage, both under and above ground. A tramway has been laid along the hillside, round to the Green mine, and the output from the latter is now being drawn by electrical locomotives to the screens at the Dugmore mine.

It is the intention to extend this tramway round to the Byrne mine, so that in the future all the coal mined can be taken to the Dugmore mine, and there screened and mixed, so that a perfectly uniform product may be obtained

There are a number of shafts from 150 to 200 feet in depth on the plateau by which ventilation is provided. A large number of borings have been put down with the diamond drill, and the continuity of the seam proved within the area of the Camp.

On the north there is a large crescent-shaped ridge of dolerite, formed by the outcrop of a sheet which dips inwards at a comparatively low angle below the mine workings. Taking into account this dip and also reckoning the distance to which the coal will be found altered by the intrusion, it is readily seen that a considerable extent of the mining area will be unproductive. Along the railway at the spot where the Doorn River passes through a narrow gorge the intrusion is very clearly exposed, the strata being faulted. A little higher up, on the plateau, a borehole passed into the dolerite at 150 feet. On the north, Dunn's borehole No. 5 (**6,** 11) penetrated 36 feet of coarse sandstone, and encountered the same intrusion. Galloway's borehole, No. 1, was actually started in the sheet itself, and was abandoned after penetrating over 95 feet of hard jointed dolerite (**13,** 29-34). The east workings in the Dugmore mine have been stopped in coal which shows signs of alteration by heat, and dolerite has been proved in a borehole 400 yards to the north-east of the limit of these workings. Thus the limit of workable coal can be obtained with fair accuracy, due allowance being made for the presence of dolerite dykes, which commonly renders the coal for no small distance on either side unsaleable.

Erosion of Seam.—The Indwe seam is composed of a number of bands of coal and shale, which are constant in character throughout the mining area. The total thickness of the seam

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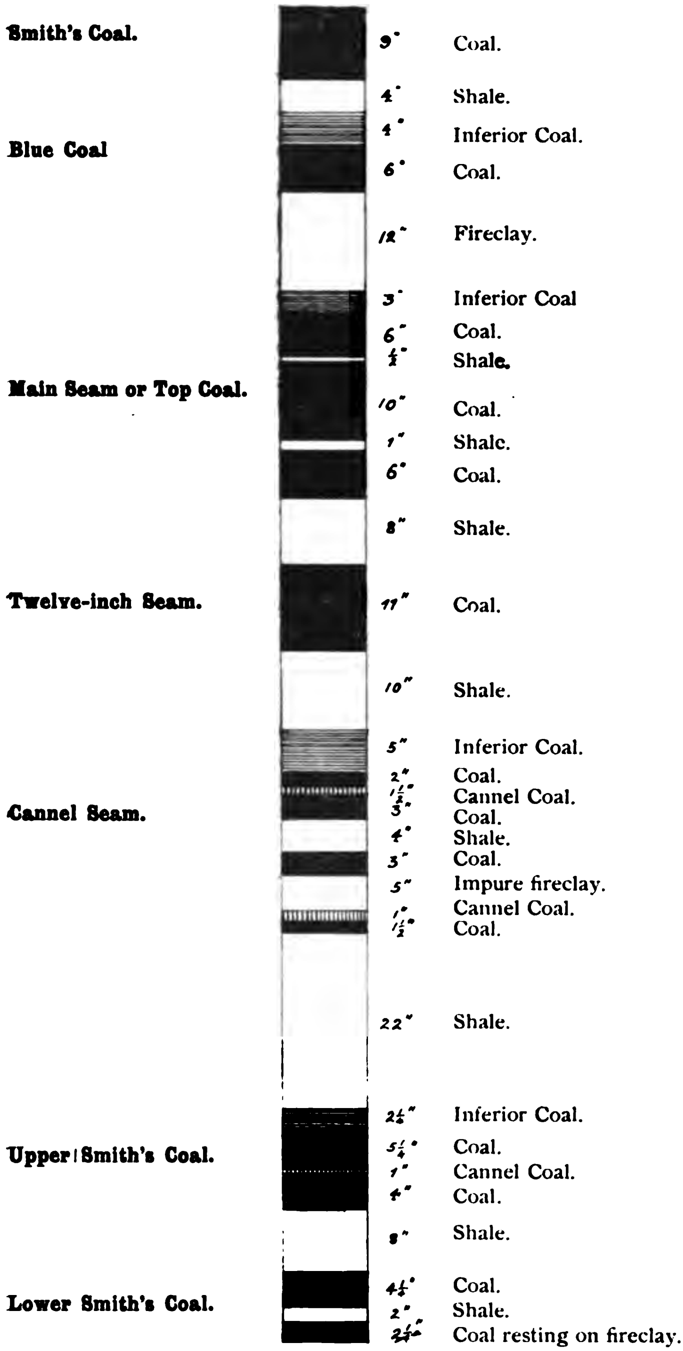

FIG. 1.—Section of Indwe Seam in Green Mine ; thickness, 14 feet.

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varies considerably from point to point, according to the presence or absence of its upper portion. The erosion of the seam was clearly pointed out by Green (7, plate), for he plotted to the same scale a number of sections taken at different points along the outcrop, and thus was enabled to identify the various layers of coal and shale.

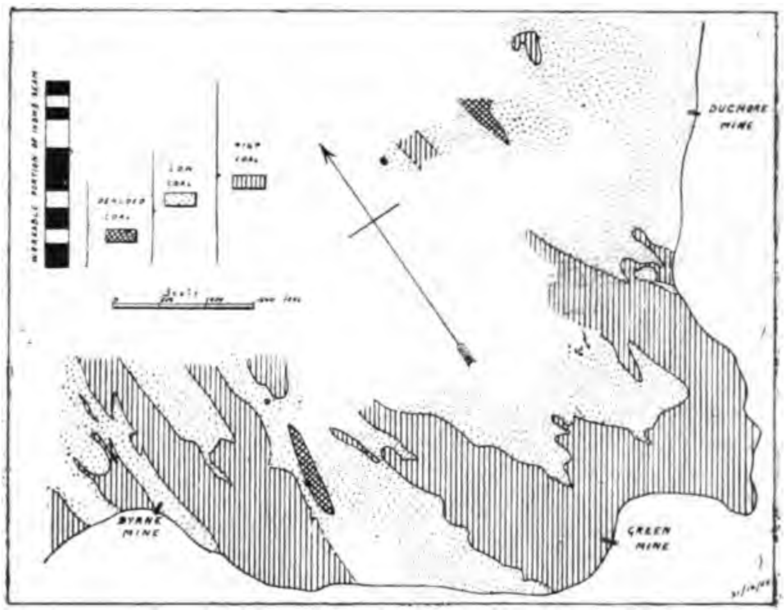

FIG. 2.—Plan of portion of the Indwe Colliery showing areas over which denuded coal is present.

There can be no doubt that these layers extended continuously over the whole of the mining area, and that the upper ones were in certain spots removed by what is termed "contemporaneous erosion," sediment being deposited in the place of the material removed.

This section (Fig. 1), taken from the Green mine, may be looked upon as typical of the coal seam in its entirety; later on certain variations will be pointed out. The thickness of the top (or smith's) coal is in a few places as much as 9 inches, but as the base of the overlying sandstone is wavy and undulating, it is probable that originally its thickness was greater. Perhaps there may even at once time have been higher layers of coal and shale, but as yet they have not been found either in the mine workings or in borings.

The degree of erosion of the seam is most important from a mining point of view, for the two upper coals are of excellent quality, and their absence means a considerable loss.

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In Figure 2, taken from a map made by the Indwe Company, the degree of denudation of the seam is given as far as the workings have extended.

Three degrees of erosion are recognised:—

(1) "*High coal*," in which a portion or the whole of the two uppermost seams is present. This condition is to be found principally in the Byrne and Green mines, and the average quality of the output is therefore high;

(2) "*Low coal*," in which erosion has removed a greater or less amount of the main seam. This condition is found throughout almost the whole of the workings of the Dugmore mine; while boring records show that the same condition exists in the unworked area to the north. Little patches of "high coal" will no doubt be present here and there, as, for example, in the small area due north of the Dugmore mine;

(3) "*Denuded coal*," in which practically the whole of the main seam has disappeared, while even some of the shale above the twelve-inch seam may have been removed. Only two small areas of "denuded coal" have yet been proved in the workings, but as we shall have occasion to point out later, outside the Camp area the Indwe seam is often very much denuded.

From Fig. 2 it will be noticed that these "wash-outs" have a general trend a little to the west of north. Similar "wash-outs" are not uncommon in the British coal-fields—for instance, in the Forest of Dean,† and they must have been caused by streams or currents of water flowing over the seam of coal and shale while they were yet in a soft incoherent state.

The seam at Indwe does not lie horizontally; in addition to the general north-north-easterly dip, which has been given to the beds after their formation, there are also minor undulations, which seem to be an original feature. Apparently the sandstone underlying the seam was not deposited in a perfectly smooth and regular manner, and the thin layers of coal and shale were spread over the undulating surface and perpetuated the irregularities beneath them. At the conclusion of the formation of the seam currents of water carrying gritty sediment swept over the soft carbonaceous deposit. The flow of the water would be directed along the gentle troughs of the surface, and erosion would be most vigorous in the hollows. This is exactly the phenomena that Mr. Colley has noticed, for he informs me that the disappearing of the upper coals can always be predicted by the falling of the level of the lower coals, while with the rising of the level of the latter the upper coals reappear.

Generally, when the dip of the roof is rapid the erosion is deep but the width of the denuded belt narrow, and *vice versa*. Usually, again, where the sandstone in a trough abuts against eroded coal and shale, the former includes peculiar wavy strings

† A. Geikie. Text-book of Geology. Vol. I., p. 639. 1903.

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and lenticles of carbonaceous material, while away from the junction the sandstone is pure. Apparently some of the denuded material has been incorporated with the siliceous sediment. The sandstone just at the junction is often crowded with quartzite pebbles, and permeated to a great extent by iron pyrites; upon oxidation the latter tends to form a strong ferruginous cement. Very often these pebbles occur on the top of the coal, partly embedded in the latter and partly in the sandstone of the roof.

In the north-easterly workings of the Dugmore mine a layer of very evenly bedded and massive blue-black or grey shale, breaking into slabs with smooth polished faces, rests directly upon the slightly denuded main seam. It varies in thickness up to twenty inches, is followed by sandstone, and apparently covers no inconsiderable area. Otherwise the seam is always overlain directly by a thick bed of solid grey sandstone.

Character of Seam.—The various coals which go to form the Indwe seam are of very different thickness and quality.

The *Lower Smith's Coal* is rather impure, but the *Upper Smith's Coal* is of good quality; both coals improve when followed from the Byrne to the Dugmore mine; in the workings of the latter these coals evolve a small amount of firedamp. Owing to the thick bed of overlying shale, the seams cannot be mined economically, and are always left in the workings.

In the *Cannel Seam* the only part worth extracting is the upper portion of from six to seven inches, including a layer of cannel coal from one to two inches thick. Although so thin, this coal forms one of the best portions of the Indwe seam; it is sent out separately from the workings and hand-picked, as the different layers of coal and shale adhere rather firmly.

The *Twelve-inch Seam* is a hard, massive coal, without any partings.

The *Main Seam or Top Coal* is usually rather impure for a few inches at the very top. Then comes from twelve to fifteen inches of hard coal, which, when affected by a dolerite intrusion, exhibits two marked vertical cleavages, and is then known as "square-face." The lowest four inches are very bituminous, and when altered by dolerite, acquire a bright crystalline appearance.

In exceptional cases the seam may reach a thickness of 27 inches; usually it is about 22, and there are nearly always two thin partings of shale or very impure coal.

The *Blue Coal* is bituminous, and very constant in thickness. On the other hand, the fireclay parting between it and the Main Seam is rather variable, its thickness ranging from one to thirty inches, though on an average it is about one foot thick. Molyneux (**5**, 26) records the finding of a quartzite boulder 14 inches long embedded in this fireclay.

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The *Smith's Coal* is good, and bituminous in character. With regard to the quality of the Indwe coal, the only analyses that have apparently been made are by Dr. Hahn, published in Galloway's Report (**9,** 20), and again in Bain (**15,** 26). The three analyses refer respectively to the Smith's (or perhaps the Blue) Coal, the Main Seam, and the Twelve-inch Seam; the analyses, given in Dunn's Report (**3,** 36) are only partial. Far more reliable are tests made with a calorimeter, for it is often impossible to determine the value of a coal from an analysis only.

Innumerable tests have been made by the Railway Department in comparing the relative values of Indwe, Stormberg, and Welsh coals. The principal tests will be found in **8,** 20; **9,** 39 and 50; **10,** 4; **11,** 56, 57; **13,** 44. The latest tests on the Railway give an evaporative power of 5.49 pounds of water with one pound of Indwe coal, as compared with 7.70 and 8.39 pounds of water for two different samples of Welsh coal.

Alteration of Coal.—The coal in the Camp area is often altered by the intrusion of dolerite dykes through the strata. The distance to which this alteration extends, due to the partial or complete loss of the volatile hydrocarbons, is very variable. This may be so even for dykes of similar thicknesses, showing that the molten rock at the instant of injection must have varied considerably in temperature in the different intrusions. The dolerite of the larger dykes is quite fresh and unchanged right up to the contact with the coal, but dykes and sills a few inches wide have usually been converted into "white-trap," which often decomposes, to form a white or yellow clay. Columnar structure is commonly developed in the coke produced by the igneous rock. The objection to this anthracitic coal, or "burnt" coal, as it is commonly termed, is that it develops an intense heat during combustion, which tends to fuse the ash and form clinker.

Strata Above Seam.—The thickness of grey felspathic sandstone overlying the Indwe Seam is about 75 feet, and it then gives place suddenly to a coarse pebbly sandstone, containing the band of ironstone-conglomerate known as the "oyster-bed." It is this thick pebbly sandstone, often false-bedded, that has been called the Indwe sandstone, and that forms such a reliable bench-mark in the Molteno beds. At the base of this sandstone there is found in places in the Camp area a thin impure coal, usually not more than 15 inches thick, known as the "Flying" seam. It is the representative of the Guba Seam, a coal which attains its full section to the west of Indwe.

It is worth noticing that usually when the Indwe Seam is present at any point, the Guba Seam will be absent, and *vice versa.* In only a few localities are both seams developed, and when that is the case, commonly either one or both have deteriorated considerably in thickness and quality.

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Area Without the Camp.—It has already been recorded that a sheet of dolerite underlies the Camp area. The outcrop can be followed along the circumference of a circle about five miles in diameter, in which the town of Indwe is almost at the centre. The strata resting upon this basin-shaped sheet of dolerite have been faulted upwards, the displacement varying from one to two hundred feet.

The intrusion crosses the Indwe River at a point just east of the Dugmore mine, and beyond it the Indwe sandstone is found cropping out on either bank, for a distance of a couple of hundred yards. A borehole almost in the bed of the river struck the Indwe Coal at a depth of eight feet, the seam being considerably denuded.

On the farm Tarka, the Indwe sandstone reappears from beneath the dolerite, in the narrow winding valley along which the road to Cala has been cut. A borehole put down by the Indwe Company near the lower end of the valley penetrated the Indwe Coal at a depth of 107 feet, the seam being denuded to the condition known as "low" coal. The boring was continued in Molteno beds, but abandoned at a depth of 457 feet, after penetrating 21 feet into dolerite. The strata are here on the downthrow side of the fault. Higher up the valley, and to the north, there is exposed a thin, impure coal, which corresponds in horizon to that of the Cala Pass and Newcastle coals. At a slightly higher level, there occurs a bed of hard flinty rock, not more than nine inches thick, and crowded with well-preserved remains of *Thinnfeldia*, *Taeniopteris*, and *Baiera*. It is identical both in characters and geological position with a similar fossiliferous bed, found on the farm Koning's Kroon, in the Elliot* Division.

There is a very large amount of dolerite on Tarka, and, in fact, all along the left bank of the Indwe River, as far north as Roode Hoogte.

In the south-west of Lichfield (lot A), the Indwe sandstone forms a precipice, crowned with dolerite, overlooking the plain of the Indwe River. At a point just behind the homestead, known as the Indwe Farm, a seam of coal was opened out by Mr. Galloway by means of a drive eighteen yards in length. The section given (**9,** 16) does not exactly correspond to that at the Indwe mine, but there can be no doubt that it must represent the Indwe Seam. The coal is anthracitic, due possibly to the overlying dolerite, but perhaps more probably to a vertical dolerite dyke, striking north and south, and cutting through the coal on the right of the adit. A more unsuitable position for an opening could hardly be found, for this intrusion marks a line of fault, with downthrow of about a hundred feet to the east. The strata dip to the north-north-east at an angle of about two degrees.

* Ann. Rept. Geol. Comm. for 1903, p. 187.

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The overlying sheet of dolerite extends some distance to the north-east before it dips below the surface, and it is quite possible that the seam extends in an unaltered condition for a fair distance, perhaps continuously to Tarka and Cradock, but there is always the possibility of unsuspected dolerite intrusions.

A number of boreholes were put down on Lichfield, upon a horizon considerably above that of the coal. In the majority of instances, however, the great sheet of dolerite was encountered.

On the farms Drooge and Vlakte, on the other hand, eleven boreholes were put down by the Indwe Company, and coals proved in most of them. The area is fairly free from dolerite, and slopes gently to the north, the inclination being slightly less than the dip of the strata. Seven of the holes were arranged along a straight line, and the same coal seams struck in all, except in Number 8.

This penetrated dolerite at 130 feet, and as there is a discrepancy between the levels of the coals in the adjacent boreholes Numbers 6 and 9, it is probable that the dolerite marks a line of fault with a moderate downthrow to the north.

The lower seam was met with at from 175 to 215 feet from the surface usually; above it comes from 35 to 45 feet of sandstone, shale, and mudstone, and then the "flying" seam, which is in turn overlain by about 100 feet of grey sandstone.

The "flying" seam is very variable in character, but appears to include one good band of coal, about a foot thick. The lower seam includes two layers of coal, about 11 and 14 inches respectively.

It is only by sinking a shaft that the real thickness and quality of the coal can be determined, and perhaps it may prove possible to work these seams. There is dolerite to the south and west of this area, and thin sheet-like intrusions have penetrated both seams in No. 10, but there appears to be an extent of several square miles over which the coal has been proved, while a considerable portion of the same two farms lying north of the railway has not yet been tested.

There can be no doubt that these coals are on a considerably higher horizon, geologically, than that at the Camp.

In the first place, the Red beds crop out on the face of the ridge to the north, so that the lower seam must lie on a horizon about 350 or 400 feet below the base of that formation. Secondly, the borehole Number 3 reached a depth of 802 feet, all in Molteno beds, the boring being discontinued owing to the jamming of the crown. The 613 feet of beds below the coal seam were principally coarse grey sandstones, with thin bands of mudstone and shale, often coaly and crowded with plant remains. The borehole terminated in coarse grey sandstone.

As the core has not been preserved, it is impossible to say whether the boring is entirely in beds above the Indwe sandstone or not, but I am inclined to the view that the horizon of the Indwe seam has been penetrated at a depth of about 600

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feet, and that the Indwe coal is not developed in this locality. This great depth is due partly to the cumulative effects of downthrow faults produced by dolerite intrusion, and partly to the increased northerly dip of the strata; on Cradock, the inclination is as much as five degrees.

Turning now to the area north-west of Indwe, we find that along the Doorn River, just beyond the "poort," the strata are faulted down by the dolerite intrusion. The Indwe seam is evidently continuous from the Byrne mine, and has been exposed in several openings on the left bank of the river. The most important of these drives is known as Trennery's, and a section of the seam is given by Galloway (**9**, 18), also an analysis of the coal (p. 13). It is evident that the seam is here denuded to less than two-fifths its full thickness. In a borehole put down by the Indwe Company to the rear of the opening, the seam is less denuded, but only one-third of the main seam has escaped erosion.

Higher up the Doorn River, almost on the northern boundary of Doornkop, the stream is crossed by a dolerite dyke, which faults the Indwe sandstone and coal downwards to the north, a distance of about 50 or 60 feet.

As the dyke is followed across Perseke Plaats, the throw of the fault diminishes. On the east, the dyke extends across Koorn Hoek, and its extension is probably the intrusion seen crossing the "Remaining portion of the Camp," joining up with the dolerite mass on the Indwe River. The strata at a point between the road and the river are much tilted at the contact with the north side of the dyke, so that it is very likely that the throw of the fault is greater here than on the Doorn River. A borehole put down by the Indwe Company to the north of the dyke, close to the railway, reached a depth of 569 feet, but only traces of coal were met with about half-way down. Two dolerite sills were penetrated, and the boring terminated in dolerite.

Here, again, it is difficult to decide whether the Indwe coal horizon has been passed through, or whether it lies at a still greater depth. The surface at the top of the borehole is about 31 feet lower than the opening at the Green mine; from the latter, the seam falls about 200 feet to the dolerite sheet forming the boundary of the camp. This faults down the beds beyond fully 150 feet, perhaps more, after which we find the vertical dyke from Perseke Plaats, which gives a downthrow of probably 100 feet at the least. The strata also dip at a greater rate hereabouts, so that the minimum depth of the horizon of the Indwe seam would probably be not less than 550 feet. It is possible that the seam may have been completely denuded, or else it may have been replaced by dolerite. It is worth noting that on the Doorn River the dolerite dyke occupying the line of fault is seen to give off thin sheets, which penetrate the coal seam on either side of it.

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The prospect of workable coal on Koorn Hoek, Remainder of Camp, Middlecourt, and Stil Fontein is very small. Not only will the Indwe seam, if present, be found at a considerable depth, but there is evidence of great igneous masses intruded into the strata below. From Perseke Plaats, over to Middlecourt, there is a peculiar intrusion of dolerite, which projects at intervals through the strata in dome-shaped masses, but which is evidently continuous below ground.

The borehole Number 4, put down by Dunn at some distance from any visible intrusion (on Middlecourt), entered dolerite at a depth of 162 feet. The igneous rock probably extends underground to the north, for another borehole, almost on the boundary between Jonas' Hoek and Koorn Hoek, penetrated dolerite at 125 feet.

North-eastwards, on Koorn Hoek, Stil Fontein, and Onverwacht, the Molteno beds are hidden by thick grass-covered soil.

On Roode Hoogte, a borehole was put down by North (**4**, 8), just below the base of the Red beds, and an eighteen-inch seam of coal proved at a depth of 80 feet. This is probably one of the highest seams known to occur in the formation.

On Doornkop and Perseke Plaats, a considerable amount of development was carried out, principally under Mr. Galloway's direction. The little plateau north of the railway has been proved by four drives, usually known as "Ferguson's Openings." A large scale plan and a detailed report upon the drives, including results of tests made with the coals, will be found in **11.**

The coal is the Indwe Seam, much denuded, and, as a whole, somewhat inferior in quality to that at the Camp. In some parts of the area as much as half of the main seam still remains, but elsewhere it has wholly disappeared. The seam overlying the two-foot shale band in the sections accompanying the report (**11,** plates 3 and 6) must correspond to the Cannel Seam of the Camp. Actually, it is so mixed with shale that it would not be worth mining. The only coal, therefore, worth extracting will be the two seams below it, aggregating 20 inches.

The dip of the strata is to the north-east, at first gently and then steeper, but a thin dolerite sill (from the Perseke Plaats-Koorn Hoek dyke) has completely replaced the seam in Number 4 drive, and will probably be found in the western workings also.

A borehole on top of the plateau penetrated the Indwe sandstone, and at 35 feet provide thin black shales, which represent the Guba coal horizon (**11,** plate 9).

The strata dip rather rapidly in the east corner of Perseke Plaats, and a borehole (No. 3) put down by Dunn (**6,** 10) has evidently just failed to reach the Indwe seam, though the Guba horizon was marked by a layer of impure coal, fifteen inches thick. A deepening of this hole by a few feet would

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probably prove the Indwe Seam. About half a mile to the north-east (but on the farm Jonas' Hoek), a borehole sunk by the Indwe Company reached the Indwe Seam at a depth of 266 feet, the coals below the main seam being alone represented.

The strata continue to dip north-eastwards, hence Dunn's No. 2 borehole, 102 feet deep (**6,** 10) did not reach the Indwe horizon. The core, however, showed that the anticlinal sheet of dolerite, which crops out a little to the north-west, dips downwards to the south-east below Perseke Plaats and Jonas' Hoek (see fig. 3). The available area of coal will probably be rather small.

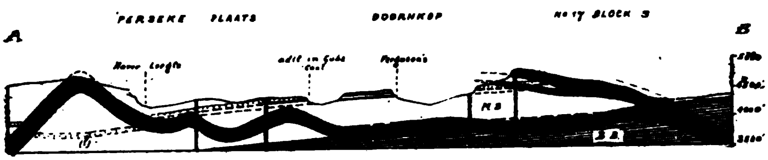

FIG. 3.—Section along line. A B on map, length 6 miles; M.B., Molteno beds; B.B., Burghersdorp beds; intrusive dolerite coloured black.

On Perseke Plaats, almost on the Doornkop boundary, there are two long drives, about 60 yards apart, which expose the Guba coal. Resting upon soft sandstones, there comes a layer of coal, about two feet thick, followed by thin beds of shale and impure coal. This very thick coal at the bottom of the seam is most distinctive of the Guba horizon, and consequently renders it easily distinguishable from the Indwe Seam. The roof consists of coarse grits and ferruginous sandstone, often very pebbly (the Indwe sandstone). The coal is somewhat anthracitic in character, and dolerite must be present not very far below the seam (see fig. 3). The extent of the seam cannot be very great.

As already noted, there are only about fifteen inches of coal in Dunn's No. 3 borehole, about a mile to the north-east; while beyond the Doorn River, the seam is absent. Even in the opposite direction, the coal apparently disappears before the great dolerite mass of Perseke Plaats is reached.

Almost due south however, on Doornkop, the Guba Coal has been opened out just below the Indwe sandstone in an adit known as Hadow's Opening (opening J. of Galloway (**11,** plate 3); see analysis in **9,** 13).

The section shows a basal seam 23 inches thick, overlain by four thin coals, from 3 to 6 inches thick, parted by black shale.

The Indwe sandstone forming the roof is very coarse-grained, and is crowded with ferruginous nodules, often of large size; while pebbles of vein quartz up to one inch in diameter and

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large boulders of quartzite are most abundant. About three feet above the seam the ferruginous nodules are concentrated to form the layer known as the "oyster-bed."

A borehole, put down by the Indwe Company, about 100 yards behind the opening, penetrated this coal at 20 feet, and the Indwe Seam at 112 feet, the two coals being separated by 87 feet of bluish-grey felspathic sandstone. This is one of few places in which both seams are present.

The Indwe Coal is not of very good quality, and the greater portion of the main seam is missing. Boreholes put down further west show that the Guba Coal disappears in that direction; the Indwe seam continues, but in a more denuded condition. Beyond the series of bends on the railway, borings have indicated the underground extension of the Perseke Plaats dolerite sheet (see fig. 3).

The dolerite "anticline," which stretches from Jonas' Hoek southwards, rises in that direction, and on the west end of Doornkop the strata beneath the arch are exposed. One "limb" turns westwards, past Umhlanga Station, and forms the boundary ridge between Wodehouse and Glen Grey for many miles; while the other turns southwards into Macubeni (Glen Grey).

The strata in the basin drained by the Cacadu River are on a horizon above the Indwe Coal; in fact, on No. 6, block 4 (Glen Grey), the Red beds appear beneath the dolerite along the Wodehouse boundary.

North of the intrusion, lower strata are met with, owing to the displacing action of the dolerite, and the Indwe sandstone forms an inlier in the valley of the Haver Leegte.

In the north-eastern corner of Vlakte Fontein, an adit exposes the Guba Coal, and a shaft put down at the same spot reached the Indwe seam, which was too anthracitic to be worth working. Boreholes on Riet Spruit passed into dolerite, and it is evident that the northern limb of the dolerite "anticline" extends below Umhlanga's Location, with a very low dip to the northward.

Along the left bank of the Haver Leegte, the Indwe sandstone forms a cliff, at the foot of which (on Catherine's Post) the Indwe Seam has been exposed in several old openings. The coal appears to be denuded, but at the same time there seems to have been irregularities in deposition, and shales may pass laterally into coal or sandstone. This variability of the seam was also noted by Dunn (**6,** 11).

On Brak Leegte, there are two adits exposing the Guba Seam, but in boreholes to the north and south this coal is absent, and only the Indwe Seam was represented.

A shaft was sunk by a Scotch syndicate to cut the latter, but I was not able to measure the section of the seams. From the information given me by Mr. Botha, the owner of the farm, there

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are three seams, 24 inches, 9 inches, and 8 inches respectively, corresponding evidently to the three lowest seams at Indwe. It is certain that we have here the very much denuded Indwe Seam, but it is possible that a greater thickness of coal and shale may be present underlying other parts of this locality.

Further up the Haver Leegte higher beds of the Molteno series are met with, and they form an escarpment along the face of which the railway has been carried; in the numerous cuttings fine sections are exposed, but no coals appear to be present. Outliers of Red beds are seen towards the north-west and south-west.

Further down the Haver Leegte, the strata dip rapidly to the east and north-east, and the Indwe sandstone is succeeded by higher beds. On Spioen Kop, Dunn put down a borehole (Number 1), a little above the drift on the main road from Dordrecht to Indwe (**6,** 10), but it is evident that the horizon of the coal must be at least 500 feet below this point.

In places along the river bank the "glittering" sandstones have had their component quartz grains cemented by chalcedonic silica. The rock is then very hard, and weathers to a paler tint than the normal sandstone. At the top of the ridge overlooking the drift there is a thin bed of yellow friable sandstone, crowded with pebbles, and becoming in places a conglomerate. The pebbles vary from half an inch up to a foot in length, are very smooth, and consist chiefly of various types of hard quartzites, but grits, hard white slates, and a pebble of quartz-felsite were also seen.

Turning attention now to the area lying south of Indwe, we find a few miles distant from the town three prominent kopjes, overlooking the plain of the Guba River. On their northern sides there is a dolerite sheet, and the summits of the three hills are partially capped with dolerite.

On the easternmost hill, the position of the Indwe Seam is now indicated by small exposures of impure coal and shale, the old opening being hardly visible; while higher up, small weathered fragments of dark shale mark the horizon of the Guba Coal.

Galloway (**9,** T. p. 13) gives the thickness of the coal. The dolerite sheet has altered the strata considerably; the shales are converted to hard black porcellanite, while the coarse Indwe sandstone has been rendered finely prismatic, the columns being as much as four feet in length and about six inches across. The second hill is similar to the first.

About 10 miles south of Indwe there is a long ridge, formed of Molteno beds, stretching eastwards from the head of the Guba River to the Indwe Poort (Trennery's). On one of the highest elevations, which forms the boundary between Nos. 7B, block 3, and 11B, block 2, is situated Holland's mine.

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The Indwe sandstone forms a plateau, diamond-shaped in plan, from which rise two detached dolerite crowned hills. In the easternmost of these elevations there are two drives, one on the north-east and the other on the south-east, exposing a compound seam of coal and shale, which in geological position corresponds to that of the Cala Pass coals. Galloway (**9**, 18) has given a section of the coal which is platy or laminated, and which in places is coked and shiny, owing to thin dolerite sheets given off from a dyke which cuts through the hill. The thick pebbly sandstone some distance above the coal corresponds very probably to the Gubenxa sandstone in the Elliot Division. Below the Indwe sandstone, no coal is found on the north side of the plateau, but on the south-west side, overlooking the Donga Stream, is an adit exposing the Guba Seam. Probably this is the opening referred to by Molyneux (**5**, 25), as the section he gives agrees with that exposed at this locality.

About a mile nearly due north of Holland's mine, there is an outlying mass of Indwe sandstone, which has been rendered finely columnar by a sheet of dolerite cutting obliquely through it.

Guba Valley.—The high ground separating the valleys of the Guba and Cacadu Rivers, from a spot overlooking Lady Frere to as far north as Doornkop, is a great dolerite-capped plateau, which has been deeply trenched by rivers. The intrusion has generally occurred on a horizon just above the Indwe sandstone, but in several places the base of the sheet rises a bit above that level. The feeders of the sheet can often be traced, and their existence underneath the capping of dolerite is a most important factor to be reckoned with in working any of the coals which occur in this area. One of the most important of these feeders is the large inclined sheet, with easterly dip, running from No. 13, block 3, to No. 11A, block 2 (the Donga Mountain), where it changes its direction and turns westwards towards Mount Arthur (Glen Grey).

In the Guba valley coals are, or rather were, exposed at a number of points, for most of the openings seem to have fallen in at some time previous to my visit.

The localities of these openings are indicated on maps accompanying the Reports of Mr. Galloway (**10**) and Mr. Tilney (**8**), while the total thicknesses of the coaly layers, and occasionally an analysis, are given in the first-mentioned paper.

The prospects on the right side of the valley, *e.g.*, Nos. 10C, block 3, 9B, block 3, are not encouraging, owing to the limited width of the ridge. On the latter farm is the opening known as Jacob's mine, which shows a total thickness of 30 inches of good bituminous coal.

On No. 8, block 3, and No. 9A, block 3, there is a considerable area covered by the Indwe sandstone, but no openings have been made to prove the existence of any seam.

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In the middle of the Guba valley there is an isolated narrow ridge of Indwe sandstone, on the east side of which is Murray's Mine.

The coal is bituminous, and the seam, curiously enough, is on the Indwe horizon. All the other openings in the valley are in the Guba Coal, but the latter is absent above Murray's Mine.

On the left side of the Guba valley, towards its upper end, it is very unlikely that bituminous coal will be found. Along the left bank of the river, for a distance of four miles, dolerite is exposed; just a portion of the convex surface of a sheet coming out of the river-bed, and rising gradually to the north-west. It probably extends underground in that direction, and joins up with the overlying sheet crowning the plateau.

On No. 10B, block 3, was the exposure known as Bradfield's Opening; this is the Guba Seam, containing 2 feet 11 inches of coal, which, according to Galloway (**9**, 13), is a free-burning anthracite. The overlying dolerite is separated from the coal by a very small amount of sandstone, so that this character of the coal is only to be expected.

In the valley to the north, No. 13, block 3, a considerable thickness of strata intervenes, and in the opening known as No. 4 Guba, the coal is of better quality (**9**, 13). Should the seam be continuous between the two openings, as is very probable, it is likely that this area may be worth working. Almost opposite No. 4 Guba is the adit known as Tilney's opening, the coal of which contains nearly 32% of ash (**9**, 13).

The seam is probably continuous down the left-hand side of the valley underlying the area on the map marked "Mineral Lease." Towards the head of the narrow kloof, to the west of this, a drive once again exposes the seam overlain by the pebbly Indwe sandstone. At this point the overlying dolerite comes down rather low, and there is also a little feeder in a branch ravine to the west. The seam is evidently continuous towards the north below No. 14, block 3, and is exposed in two important drives, known as Rimmel's Openings, in the valley leading down to the Doorn River.

The following is a section of the seam:—

Sandstone	Forming roof.
Shale	9 inches.
Coal	7 „
Shale	2 „
Coal	3 „
Impure coal	3 „
Coal	7 „
Shale	1 „
Impure coal	4 „
Coal	25 „
Shale	Floor.

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There is consequently a series of thin coals above, and a solid seam of coal, just over two feet thick, below. The roof is the coarse Indwe sandstone, with numerous quartzite boulders and ferruginous concretions. A few hundred yards along the hillside, below a small waterfall, the seam crops out naturally; the exposure is known as the Sheba. There is a thin dolerite intrusion, and the coal is slightly anthracitic (**9,** 16). Towards the north end of the valley, the seam has also been proved, but it is very anthracitic; the same is the case on the north-east.

The Indwe coal may or may not be present in the valley, and it may, perhaps, be worth while making one or two openings below Rimmel's to determine this point. A borehole over 300 feet deep was sunk in the valley, but it started at too low a level. The strata proved were grey sandstones, with thin bands of dark shale.

On the hillside, about 150 feet above the coal horizon at Rimmel's Openings, is an outcrop of shales and mudstones and impure laminated coals, just a little below the dolerite. The shales are crowded with plant remains, and the horizon corresponds with that of the Cala Pass coals (*e.g.*, Tarka and Holland's mine).

Cacadu Valley.—In the valley of the Cacadu River, in the ward of Macubeni, the Indwe sandstone crops out again, and in several localities the presence of one or more seams of coal below it have been proved.

In the north part of No. 1, block 4, there is an opening in the Guba seam, showing a 26-inch band of coal, followed by 3 inches of shale, and then by 6 inches of coal; the full section is given by Galloway (**11,** 3, sect. 1). A second opening, with almost identical section, occurs further to the west.

Below the first opening, in a deep channel cut by a small stream, there is an outcrop of the Indwe Seam, which is very much weathered and of poor quality. The same coal is exposed in a drive a little to the west. About 80 feet of fine-grained sandstone parts the two coal horizons

It is most probable that the Guba Seam, overlain by sandstone and dolerite, extends from this point right through to Rimmel's Openings and those on No. 13, block 3. As shown in the section (fig. 4), the dolerite sheet arches upward slightly, and the coal underlying it will be free from any injurious effect.

A most important question, however, is the presence of any dolerite sills underground, but there are apparently only two intrusions of any importance that may encroach on this area. The first is the southern limb of the Perseke Plaats "anticline," which passes through Doornkop and No. 3, block 4, and forms the northern edge of No. 14, block 3, the dip being south-easterly. It then turns westward into No. 2, block 4, and after that southward into No. 8, block 4, where it faults down the Indwe sandstone, a distance of at least 150 feet to the west.

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On No. 1, block 4, it unites with a sheet of dolerite coming up from the east, an intrusion which will pass below either the north-western or the south-western corner of the mineral lease on No. 14, block 3, depending upon whether it runs in a straight line or in a curve. It will also mark a fault with upthrow to the south-east.

In whatever direction it may run, I think that there will be an area of at least one square mile below which the Guba coal will be present in an unaltered condition. To settle this absolutely would require the sinking of a borehole about a mile behind Rimmel's openings. The hole would pass through about 150 feet of dolerite, and reach the coal at not less than 400 feet. A carefully levelled section would be required to determine the depth exactly.

There would be no difficulty in working the coal from Rimmel's openings, for the seam rises gradually towards the south-west, and a railway not many miles in length would join the main line at a point close to Umhlanga Station.

In the east portion of No. 1, block 4, there is an adit, which was opened by Thomas Zwedala, headman of Macubeni; there is so much dolerite round about that the coal will be of no value.

It has been noticed a little further back that on No. 8, block 4, the Indwe sandstone was faulted down by a dolerite sheet. This is repeated by parallel intrusion, and in consequence the sandstone forms low cliffs, fringing the banks of the Cacadu River, a couple of miles above Macubeni Trading Station. Below the Trading Station a great sill crosses the river—an extension of the Zwart Water intrusion—and produces a dislocation of fully 400 feet, with upthrow to the south. Further downstream several inclined sheets repeat the faulting action. When to this is added the northerly dip of the strata, the presence of the Indwe sandstone crowning the Donga Mountain overlooking Lady Frere finds an easy explanation.

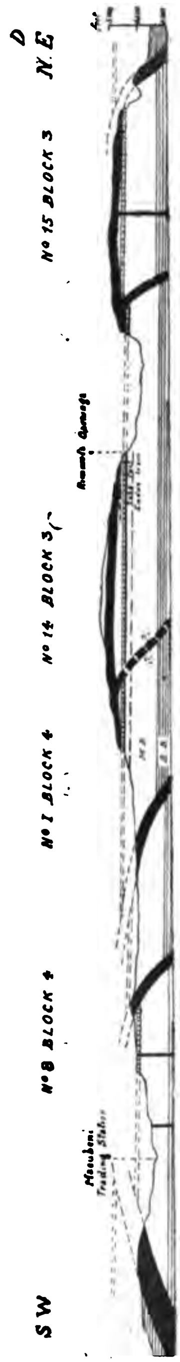

FIG 4.—Section along C.D. on map, length nearly 12 miles; M.R., Molteno beds; B.B., Burghersdorp beds; intrusive dolerite coloured black.

Transkei.—On the east side of the Indwe River the Molteno beds form the plateau of the Umtingwevu Mountains in the Division of Xalanga. Burghersdorp beds occur all along the base of the escarpment, which is crowned with the Indwe sandstone and an overlying dolerite sheet. A slight elevation on the southern edge of the plateau, known as Lubisi, has been used as a trigonometrical station, and has an altitude of 5,823 feet above sea level.*

The conical peak, Trignard's Kop, overlooking the village of Southeyville, is a little lower in altitude. The Molteno beds, so far as is yet known, here reach their southernmost limit, but the outcrops on Thaba Mtheku (Glen Grey) and Bongolo Nek (Queenstown) have almost the same latitude.

(ii). *The Area West and South-west of Dordrecht.*

From Dordrecht, Molteno beds, with occasional small outliers of Red beds, stretch southwards to the Glen Grey border. South of Tweefontein a plateau crowned by the Indwe sandstone extends for several miles into Glen Grey.

On the west side, overlooking the plain on which the trading station of Tsembeyi is situated, there is a drive exposing the Indwe Seam. The section of the seam taken by Mr. G. Hall is given by Galloway (**11,** 4). The coal is anthracitic, as can only be expected, for the whole area is underlain by the immense dolerite intrusion which stretches from Macubeni to Zwart Water.

The limited areas of Molteno beds in Zwart Water, Zingutu, Vaalbank, and Qoqodala are practically enveloped in dolerite, and there is very little possibility of any workable seams being found.

In the south-western corner of Wodehouse Molteno beds form an extensive flattish tract of country, bounded on the north by the watershed of the Stormberg and on the south by the dolerite masses of the Andriesberg.

On Middlecourt (Quagga's Fontein), Uyl Hoek, and along the Birds' River there are extensive sheets of dolerite spreading out nearly horizontally, but from Kalkoen Krans westwards to the Queenstown border the country is undulating, grass-covered, and fairly free from intrusions. In many places rounded boulders of quartzite, often of considerable size, strew the surface of the ground, having been weathered out of some of the sandstone beds.

Coal seams crop out at two localities, the first at Halseton Station, and the second about six miles to the south, on the farm Kleine Vley. At the station, about a quarter of a mile towards the west, there are two drives in the side of a flat-topped ridge.

The coal is thin, and as it contains numerous mud films is very impure; at places it is semi-anthracitic. A section is

* Sir D. Gill, Report on the Geodetic Survey of South Africa, Vol. II, p. 237. Cape Town, 1901.

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given by Green (**7**, 20). Associated with the coal is a considerable amount of fireclay, which may perhaps be of economic value. To the east the horizon can be traced until it terminates against a dolerite intrusion, which has disturbed the strata considerably. To the north-west the coal passes below a little plateau capped with a dolerite sheet, and its nature in this direction has not yet been ascertained.

Towards the south, on Stones Beacon, the same horizon, represented by black shales, mudstones, and fireclay, is found below a little ridge of gritty sandstone. At a point almost in the centre of this farm a borehole was put down to a depth of 413 feet, principally through blue-grey sandstones and shales, but only streaks of coal were discovered.

On the west side of Beaconsfield, the farm adjoining, a second borehole reached a depth of 402 feet, with a similarly negative result.

The second coal locality is a prominent elevation on the farm Kleine Vley, crowned with a bed of coarse pebbly sandstone. Just below this capping is the seam which has been proved in two drives on opposite sides of the hill, and which shows a considerable thickness of coal. The following is a section.—

Shale	15	inches.
Coal	$1\frac{1}{2}$	"
Shale	$2\frac{1}{2}$	"
Coal (impure at top)	7	"
Shale	5	"
Coal	12	"
Shale	3	"
Coal	18	"

The coal is somewhat anthracitic, this being due to the proximity of a dolerite sill, while the extent of available coal is, unfortunately, very limited. Three analyses of the coal are given in the Report (**15**, 27).

To the north-east are three flat-topped hills, capped with the same bed of sandstone, and it is possible that the seam will be found immediately below it; the openings hitherto made have all been on too low a horizon. Further east, on Middlecourt and Uyl Hoek, a dolerite sheet has been intruded just below the bed of pebbly sandstone.

It is difficult to know the exact stratigraphical horizon of these two coals; the only place where there is a continuous succession of strata is some distance to the north-west, at Penhoek, where the Red beds form the upper part of the escarpment of the Stormberg. Elsewhere the strata in this corner of Wodehouse are separated from the strata of the neighbouring areas by dolerite intrusions, occupying lines of dislocation. I incline to the view that the Kleine Vley coal lies geologically a little above that at Halseton Station, and that both belong to the upper portion of the Molteno beds.

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Openings have been made on the sides of Saltpetre Berg, a lofty ridge of Molteno beds close to Penhoek Station, but the results have not been encouraging.

(iii). *The Sterkstroom Area.*

South-eastward of Sterkstroom there is a considerable stretch of mountainous country adjoining the Wodehouse boundary. The strata belong to the Molteno beds, and coals have been opened up on several farms, *e.g.*, Klopper's Fontein, Doornboom, and Vaal Krans, but the seams are always thin and of poor quality, while thick slightly-inclined sheets of dolerite are numerous. A section of the seam on Klopper's Fontein has been figured by North. (**4,** 34.)

Immediately to the east of Sterkstroom, not more than a mile from the town, there is an outcrop of the Indwe sandstone. Dolerite always overlies it, and is sometimes also intruded below it or through it. This is the continuation of the Andriesberg intrusion, and extends northwards, crowning the Donker Hoeks Berg with a magnificent palisade of columnar dolerite. In spite of the abundance of dolerite east of Sterkstroom, a very considerable amount of prospecting was carried out, partly by private individuals and partly under the direction of Mr. T. Bain, on behalf of the Government, about fifteen years ago (**13,** 35 *et seq.*). A long drive exposes coal and shale immediately below the Indwe sandstone, but a sheet of fine-grained dolerite from 3 feet 6 inches to 4 feet thick has wedged itself in at the base of the seam, and is exposed along the entire length of the drive. The coal is highly anthracitic, and fragments of coal and shale have been enveloped in the igneous rock, which, at the junction, is often in the condition known as "white trap." On the top of the little plateau two shafts have been sunk, one on either side of the fence separating the farms Jonas Kraal and Hex River, the seam being proved in both cases.

The Sterkstroom Coal is evidently the equivalent of the Guba Seam in the Indwe Area. Owing to the abundance of dolerite, the coal is always more or less anthracited, and all the samples show a high percentage of ash (**13,** 14; **15,** 27).

As the result of his visit in 1890, Mr. Sichel came to the conclusion (**14,** 6) that these properties east of Sterkstroom were, from a mining standpoint, of doubtful value, and with his views I find myself in complete agreement.

A part that does not appear to have yet been prospected is the base of Donker Hoeks Berg and the flat below it, close to the Indwe railway.

About 6 miles due north of Sterkstroom, on the farm Klap Kloof, a seam has been found which looks very promising.

A considerable amount of development has been done on the west side of the valley, and the workings are quite extensive. The seam is about 30 inches thick, with a thin shale parting

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near the top, but the coal, which is laminated, is slightly variable in character. The continuity of the seam to the south has been proved by a borehole. On the east side of the valley the same seam is exposed at a lower altitude, owing to the easterly dip of the beds. There are two shale partings towards the top of the seam, and there will be about 26 inches of coal available.

The seam is of much better quality than that in the western workings, and contains rather thick layers of glossy coal. It is highly bituminous, and yields on burning a friable white ash, without any clinker.

The following are the analyses* of the two coals made by Mr. J. G. Rose, of the Government Analytical Laboratory, from which it will be seen that the proportion of ash is rather low :—

	West workings.	East workings.
Moisture...	4·31	3·83
Volatile hydrocarbons	30·23	25·37
Fixed carbon	46·57	58·03
Ash	18·14	11·57
Sulphur	0·75	1·20

The extension of the seam towards the north has not yet been tested, but about a mile lower down the valley its presence has been proved by boring. If continuous, the coal will pass with a gentle easterly dip below the lofty escarpment forming the edge of the Molteno Division (on the farm Noitgedacht), beneath which the strata become horizontal, and then rise slowly towards the east. This area is remarkably free from dolerite, the only intrusions being a few narrow and well-defined vertical dykes.

On the west of the valley the available area of coal will probably not be very great, for in that direction occur the great dolerite sills of Bushman's Hoek. The roof above the coal consists of a variable thickness of fireclay, shales, and mudstones, varying in colour from blue to buff and pink. The thickness of fireclay ranges from 10 to 30 feet. Above these soft beds comes a coarse sandstone, which is often very ferruginous and pebbly.

The Klap Kloof coal is apparently just above the Indwe sandstone, the outcrop of the latter crossing Donker Hoek, but being quite inconspicuous.

On Klip Kraal there is a small elevation just east of the homestead, in which the Indwe seam is represented by an outcrop of shale and very impure coal, crowded with remains of *Thinnfeldia*, *Phoenicopsis*, and *Baiera*. The strata are in contact with dolerite on the north-east, and also very probably on the west, but the boundaries of the intrusions are difficult to trace across this part of the district.

* For these and for information regarding the bore-holes, I am indebted to Mr. J. W. de Kock, M.L.A.

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The farms Klip Kraal, Kraal Doorns, and the Sterkstroom Commonage are formed of strata below the Indwe sandstone, and it is very improbable that seams of any value will be found on them.

On the north-east side of Bushman's Hoek there is a lofty ridge, formed of Molteno beds, and having the continuity of the strata frequently broken by thick dolerite sheets rising out of the valley towards the east.

North-east of the homestead and about 300 feet above it in altitude, is the opening of the Bushman's Hoek mine, immediately below a thick, massive stratum of pebbly sandstone. A considerable amount of labour was spent in the development of the property, and the workings are of no small extent, but the mine has been closed down for many years.

A description of the mine is given by North (**4**, 33), accompanied by a plan of the workings and two sections of the seam. The lowest layer of coal in the seam, about two feet thick, is of very inferior quality. The section is identical with that of the Guba Coal, and like it, is directly overlain by a sandstone resembling the Indwe sandstone.

Although it is at a higher altitude than the coals on both Klap Kloof and Klip Kraal, it is in both cases separated from them by dolerite sheets, and is, I think, on a *lower* geological horizon than the former, *e.g.*, it is on that of the Guba Coal.

In the Bushman's Hoek valley itself and towards the east there is a great sheet of dolerite, by which the strata have been much displaced. Thus on Prospect Peak, in the eastern corner of Bushman's Hoek, the Indwe sandstone has an altitude of about 5,600 feet above sea level, that of the Bushman's Hoek mine is 5,100, while the coal at Sterkstroom has an altitude of 4,550. There is only a slight south-easterly dip of the strata, so that these large differences in level are almost entirely due to the effects of dolerite intrusions. The geology of this part of the country is rather complex, and an examination of those portions of the Molteno Division adjoining will have to be made before the various outcrops of coal can be ascribed to their correct geological horizons.

Below the level of the Indwe sandstone on Prospect Peak are several thin coals, which have been described by Dunn (**3**, 21), North (**4**, 33), and Molyneux (**5**, 34). By all these observers these coals have been regarded as overlying that at the Bushman's Hoek mine, but I have just pointed out that there is a drop of 500 feet between the two spots, owing to faulting.

The uppermost seam is evidently the equivalent of that at the Bushman's Hoek mine (*i.e.*, the Guba Coal). The second, 75 feet below it, must represent the Indwe Seam.

The lowest is 300 feet beneath the Indwe sandstone, and very irregular in character. This coal has also been proved on the flat between this and Sterkstroom in a well along the railway; it is evidently the lowest seam occurring in the Molteno beds

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For making a study of the nature of the deposits forming the Molteno beds no better locality could be found than the slopes of Prospect Peak, up which the railway ascends from Bushman's Hoek to Cyfergat.

The deep cuttings expose fine-grained, often highly false-bedded, felspathic sandstones in layers of considerable thickness. The irregular bedding of the deposits is also finely shown by the lenticular and wavy intercalations of shale and mudstone, while instances of contemporaneous erosion and local unconformity are numerous. The thickness of strata intervening between the Indwe sandstone and the top of the Burghersdorp beds is here fully 500 feet.

(IV). THE RED BEDS AND CAVE SANDSTONE.

These two formations occupy only a very small portion of the area surveyed, and then only on some of the higher peaks and ridges. The rocks are well exposed, to the north of Indwe, on the ridge forming the watershed between the Doorn and the Waschbank Rivers.

The Red beds are practically the same in character as in the area to the north,* but the formation is of greater thickness. The junction of these two formations is not well defined, as there are a number of thick white sandstones towards the top of the Red beds. Commonly, however, there is a bed of purple mudstone, with abundant pale, irregular quartzitic concretions, which may be taken to mark the summit of the Red beds.

The Cave sandstone is, as usual, very soft and friable, often weathering into a porous mass, with numerous minute cavities; sometimes the rock contains thin layers of mudstone, and occasionally clay-pellet conglomerate.

On the high peak on Koorn Hoek and on the ridge overlooking Jonas' Hoek the Cave sandstone forms a capping fully 500 feet thick, which is much greater than either to the north-east or north-west. No traces of the Volcanic beds were met with on the ridges west of the Waschbank Peak.

Towards Dordrecht the mountains reach a lesser altitude, while at the same time the strata rise, so that west of Brak Leegte the Red beds only occur as detached and irregular outliers.

The monoclinal fold described in the last Annual Report (p. 84) as running from Moordenaar's Hoek to the corner of Naauwpoort was followed several miles further to the southward. On Limoen Kloof, where the main road from Dordrecht to Queenstown crosses the axis of the monocline, the strata dip

* Ann. Rept. Geol. Comm. for 1904, p. 91.

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to the west-south-west (down the valley) at an angle of fifteen degrees, and the base of the Red beds is brought down about 600 feet before the strata become horizontal again.

Owing to this fold, Red beds build up the high ground on Willow Park, while north of Koups Leegte Station they form a lofty peak, known as Wolve Kop, situated on the watershed of the Colony.

From this point to Penhoek the junction with the Molteno beds is obscured by vast intrusions of dolerite. To the north the Red beds form somewhat flattish ground, with occasional ridges or flat-topped hills, and drained by tributaries of the Holle Spruit. This plateau is at an altitude of close upon 6,000 feet above sea level, and extends westwards into the Molteno Division.

North-westward of Sterkstroom, on the southern edge of this plateau, here known as the Bamboes' Mountains, there occur several small outliers of Red beds.

(V). THE VOLCANIC NECKS.

In the last Annual Report there were described from the Wodehouse Division thirteen volcanic pipes, from which the Stormberg lavas and tuffs had been ejected.

The fourteenth neck occurs on Catherine's Post, between Dordrecht and Indwe, and though the contacts with the Molteno beds are not seen, it must be about 250 yards long and about half that across.

The material plugging the neck is the usual cream-coloured sandy material, in places brownish and silicified; on the northern side it passes into a typical pale-blue tuff, full of small fragments of sandstone and shale. No inclusions of lava were noted. The pipe is cut through parallel to its longer axis by a dolerite dyke fifteen yards in width, which trends about west-north-west, and forms a prominent ridge. The tuff has been altered to white quartzite at the junction; the contacts with the intrusion show slickensides, and occasionally there is a deposit of white vein-quartz.

The fifteenth pipe, a similar tuff neck, lies almost due south of Dordrecht, on the boundary between the farms Limoen Kloof and Leeuwe Kloof.

A most curious complex of igneous and sedimentary rocks occurs on the farm Stafelberg's Vley, a few miles north-west of Bird's River Siding, and appears to mark a centre of volcanic activity.

Here are vast hills of dolerite rising to a height of over 1,500 feet above the area to the south. A small stream has cut deeply into this peculiar complex, and laid bare the interior of the mass (see fig. 5). On the south-western side the dolerite is seen dipping steeply downwards, the sandstone and shales on

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the exterior of the dome being almost horizontal, and in the interior having an inclination of about 45 degrees.

Dolerite hills hem in the little valley, and everywhere the dip of the intrusions is seen to be away from the centre.

Large areas of sedimentary rocks occur in a tilted position, and basic intrusions have been injected along and across their bedding planes. These strips of sediments dip away from the central point in a fairly regular manner, but they belong to different geological horizons. For instance, on the north-east there are massive gritty and pebbly sandstones, evidently belonging to the Molteno beds; on the west occur sandstones, with thin purple and blue shales, while on the south is a great mass of Cave sandstone fully 350 feet in thickness, with a dip to the south-east.

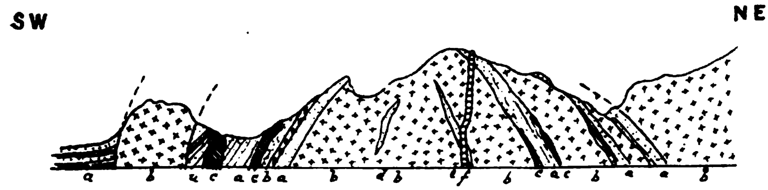

FIG. 5.—Section across complex on Stafelberg's Vley. *a*, Sandstone and shales; *b*, Karoo dolerite; *c*, intrusions earlier than *b*; *d*, hornstone; *e*, cordierite glass; *f*, intrusion later than *b*. Length of section about ¾ of a mile.

Abutting against the Cave sandstone is a mass of greenish agglomerate, with fragments of shale, sandstone, quartzite, and occasionally decomposed lava; sometimes there are patches of agglomerate in the sandstone itself.

On the west and north-west there are certain dolerite masses both sheets and bosses, which are traversed by numerous parallel joints, so that the rock very much resembles a ferruginous slate. These intrusions are for several reasons probably earlier than the Karroo dolerite, and are associated with dykes and patches of agglomerate. A thin section (1329) shows a finely porphyritic basalt, very rich in olivine, the latter being now almost completely changed to serpentine.

It is very probable that on Stafelberg's Vley we have an old volcanic centre, of Stormberg age, which was invaded at some later period by vast masses of Karroo dolerite, the sedimentary rocks being much tilted, dislocated, and portions highly metamorphosed. The finer-grained material is altered to hornstone, but some has been completely fused, and has become a cordierite glass.

The thin section (1330) shows an almost colourless, glassy base, crowded with minute cordierite crystals, which sometimes show the characteristic interpenetration trilling, and which are very usually grouped together in clusters. The slide is crowded with minute needles of some indeterminable brown mineral.

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A later dolerite dyke cuts through the whole complex in a north-west-south-east direction (see p. 139).

(VI). The Dolerites.

In this area the dolerites are on a more extensive scale, and differ somewhat in habit from the intrusions in the districts both to the north and east. There is a great tendency for a single intrusion to form a highly undulating sheet, which, on being denuded, gives rise in consequence to annular outcrops or to pseudo-laccolitic masses. Of such the Glen Grey sheet is an excellent example.

Some of the dykes apparently are a little later in age than the general period of intrusion, and consequently cut the earlier dolerites. Such intrusions are usually also basic in constitution, but narrow and more acid dykes and veins are frequently present, thus recalling characters in the dolerites of Komgha and Kentani, further to the south-east.

Sheets.—A peculiar feature, very well marked, and noticed in the area east of the Indwe River also, is the tendency for sheets of dolerite to immediately overlie the Indwe sandstone. In this way we find that the sandstone in most cases forms the scarped edges of extensive dolerite plateaux; for example, between Indwe and Lady Frere, around Cala, and in the Umtingwevu Mountains.

It is difficult to see exactly why the intrusion should take place along this rather than on any other horizon. In many places the Indwe sandstone is underlain by either the Guba or Indwe Coal, which should form a plane of weakness, and which consequently we should expect the intrusion to follow. Above the sandstone, too, we often find the equivalents of the Cala Pass Coals, but, as a rule, the level of intrusion is a little lower down.

Perhaps an explanation may be sought for in the fact that the Indwe sandstone is coarse and porous in character, and therefore likely to have contained a fair amount of moisture. This would be converted into steam by the molten dolerite, and would act as an elastic wedge in advance of it, thus determining the precise horizon of intrusion, which might to a considerable extent be independent of the cohesion of the rock.

Reference has already (p. 117) been made to the "anticlinal" sheet of dolerite on Perseke Plaats and Doornkop near Indwe, and there are a few other examples of intrusions having a similar habit.

The most unique intrusion though is an extension of the Perseke Plaats "anticline." Close to the coal-openings on the latter farm the sheet forms a dome-like mass, which, judging from the habit of similar masses, is probably a curved sheet or pseudo-laccolite. It extends underground to the Doorn River,

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where it forms a peculiar boss, on which the north-easterly beacon of Doornkop is placed. The rock pitches below ground quite suddenly, but reappears almost immediately to the east (on the farm Koornhoek).

The convex upper surface of the intrusion is visible below an escarpment of pebbly sandstones, and the dolerite must extend underground towards the north, for it has been struck in boreholes in that direction. Eastwards no dolerite is seen again until the ridge on Middlecourt is reached.

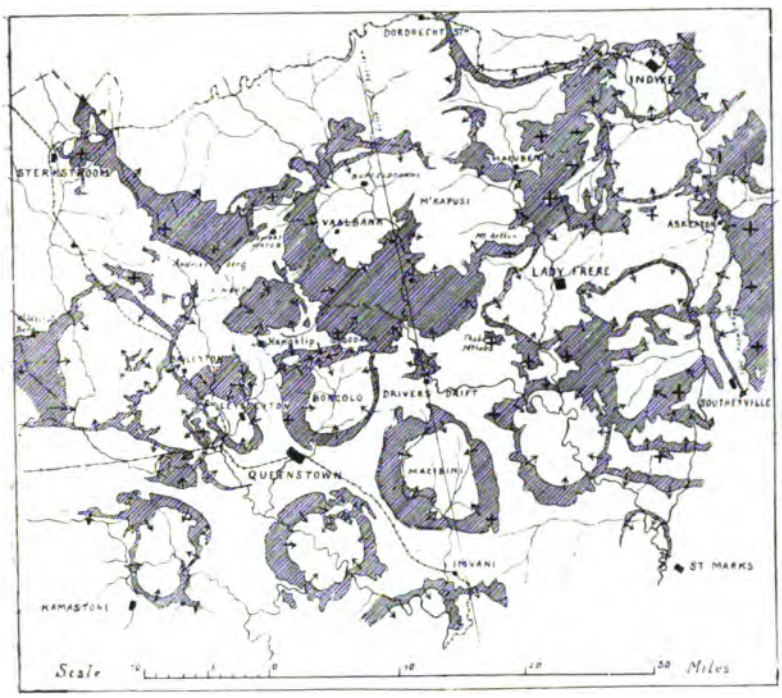

FIG. 6.—Showing the undulations of the Glen Grey dolerite sheet. The arrows indicate the direction of dip of the sheet, the crosses the places where it is horizontal.

The intrusion rises abruptly from the plain to a height of 500 feet, and in habit exactly resembles an anticline or "whaleback" of sedimentary rocks. In all directions the dolerite dips at a high angle below Molteno sandstones, which at the contacts are inclined away at angles of from 5 to 10 degrees; the dolerite was met with to the west in Dunn's No. 4 borehole. The intrusion is not a boss or solid mass of dolerite, for the crest of the ridge is denuded sufficiently to expose sandstones which form the core of the elevation.

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It is evident that there is a single intrusion, a highly irregular sheet, extending from Middlecourt to Perseke Plaats, and only now and then projecting through the sedimentary rocks.

The dolerite on Middlecourt is of the coarse ophitic type common in this area, but there are fine-grained types, giving the rock a well banded appearance, while in places there are brecciated masses.

A thin section (1319) of one of the latter shows an extremely fine-grained rock, with porphyritic crystals of plagioclase felspar and augite surrounding angular fragments of medium-grained ophitic dolerite. The junction between the two varieties is remarkably clear and sharp.

In Glen Grey and Queenstown the Glen Grey sheet, as we may call it, covers a very large extent of country, forming through irregular denudation domes and basins, often of no small diameter. In the east and north the regularity of the intrusion is broken by numerous splits and offshoots from the main mass, while towards the west the sheet is now discontinuous, owing to extensive denudation.

In fig. 6 the ramifications of this sheet are indicated, the arrows showing the directions of dip of the dolerite intrusion; a section through the same area is given in fig. 7. A brief description of the Bongolo valley, just north-east of Queenstown, will serve as a type of one of these basin-shaped hollows. This valley is about 8 miles in diameter—about the average size for one of these basins—and is hemmed in by a nearly circular ridge of dolerite. The drainage passes through a narrow gap in the south side of the ring, and an impounding reservoir is in course of construction here for the water-supply of Queenstown.

From the outside the Bongolo valley appears as a ridge from 600 to 1,500 feet in height of nearly horizontal sandstones and shales, crowned by a steep palisade of rudely columnar dolerite. In the interior the rim of the basin is produced by a slope of dolerite, with an inclination of from 15 to 45 degrees, the igneous rock dipping below the centre of the basin, which is occupied by sandstones and shales. The general appearance of one of these basins is very strikingly like that of a recent volcanic crater.

The dip slopes of dolerite are smooth and shiny, and in many places denudation has only recently removed the overlying sediments, and a thin covering of highly metamorphosed rock may still adhere to the upper surface of the sheet. It is these smooth dip slopes which led Stow† to advance the theory of a recent glaciation in the Eastern Province; his "moraines," too, consist of spheroidally weathered sheets of dolerite, *e.g.*, Bongolo Nek, Bolotwa, and Komani valley. On the north side of the Bongolo the dolerite rises rapidly, and then spreads out horizontally on the ridge overlooking the Qoqodala Mission Station; from this point it dips rapidly north-eastwards to form a similar

† I. p. 534 et seq.

basin in the Qoqodala valley. On the north-west side of the Bongolo there are two subsidiary basins in the sheet; in one of these the floor is formed of sedimentary material, but in the second the latter has been entirely removed.

The sheet then rises rapidly towards the north-west, and the finely-columnar mass crowning the lofty Hangklip is without doubt the central portion of the dome round which the basins of the Bongolo, Lesseyton, the Zingutu, and Qoqodala are grouped. Of all the basins in this area, perhaps, the most regular is the one which occurs due south of Queenstown, and which is traversed by the Zwart Kei and Klaas Smits Rivers; it shows, too, a subsidiary basin on its northern side. The basin of the Macibini due north of Imvani, is another fine example; all the drainage from this area passes through a "poort" in its southern side.

Driver's Drift is situated almost at the centre of the consequent dome, but the strata have been intensely denuded, and the White Kei River has laid bare the crown of a second dome, probably concentric with the first, and fully 2,000 feet below

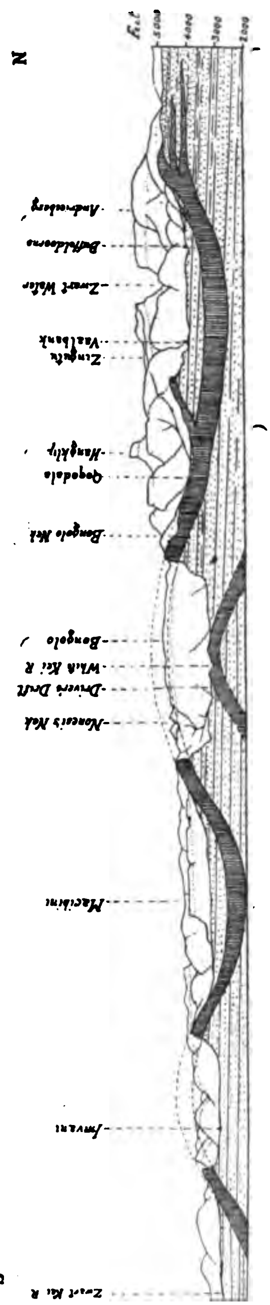

FIG. 7.—Section from Imvani to Buffeldoorns (looking west) showing the undulations of the Glen Grey dolerite sheet. Length of section 45 miles. This, taken from south to north, shows the Imvani dome and in the distance the exterior of the basin traversed by the Zwart Kei and Klaas Smit's Rivers. Then comes the Macibini Basin, the denuded dome at Driver's Drift, and the exterior of the Bongolo Basin. Further north comes the Qoqodala and Buffeldoorns Basins, with the dolerite crowned masses of Hangklip, the Zingutu and Andriesberg in the distance. The foot hills at Vaalbank and Buffeldoorns are formed by the Glen Grey sheet rising out of the valley and capping the hills beyond. The gap at Zwart Water represents a denuded dome.

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the estimated position of the latter. Towards the east a remnant of the dome in the Glen Grey sheet is seen in the remarkable dolerite-capped Thaba Mtheku.

The Qoqodala basin is floored partly with dolerite and partly with sedimentary material. The great areas occupied by hornstone and quartzite indicate the close proximity underground of the dolerite. The Qoqodala basin is only a subordinate to the great basin of Vaalbank, Buffeldoorns, Tsembeyi, and M'Kapusi, which is over 15 miles long and nearly as much across.

It is drained by two separate river systems, that of the White Kei in the west and that of the Cacadu River in the east.

On the north side the dolerite ring is not complete by about a mile; the gap is due to the splitting up of the intrusion, and the dipping of the off-shoots below the strata which form the high ground of the southern portion of Wodehouse.

There are several important points in connection with these intrusions. The first is that the top of any dome appearing in the midst of sandstone and shales will lead one to imagine the existence of a laccolite, and its real character would not be suspected unless denudation had partly revealed the interior. These pseudo-laccolites, as we may call them, will not affect the inclination of the adjoining strata to any appreciable extent, and this will explain why the sedimentary rocks maintain their normal dip up to the very contact with dolerite masses, which rise sometimes to 1,500 feet in height, and which are to all appearance laccolites having that thickness. The fact of their being hollow sheet-like intrusions will explain much.

The Glen Grey sheet varies in thickness from 200 to 500 feet, as a rule; but there is very commonly a swelling at the top of a dome, and though no section is laid bare through the bottom of a basin, it is very probable that a similar thickening exists there.

As examples of such thickenings may be mentioned the Andriesberg, in the south-west corner of Wodehouse, and the Wildschuts Berg, on the western border of Queenstown, which are crowned with horizontal masses of dolerite, about 1,500 feet and 2,000 feet thick respectively.

The inclined portions of the sheet are, as a rule, much thinner than the horizontal portions, and this is more pronounced as the inclination increases.

This can be well illustrated by simply cutting a wavy line through a piece of cardboard, and drawing the two portions a short distance apart in a vertical direction. The cardboard will represent the sedimentary rocks, and the wavy opening the space occupied by dolerite.

The variation in level of the Glen Grey sheet is often very considerable, even within a very short distance; for example, between Hangklip and Lesseyton, a distance of not more than 7 miles, the drop is over 3,500 feet.

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The intrusion has always produced dislocation of the sedimentary rocks, and the amount of displacement is often considerable, the beds above the dolerite being raised relatively to those below. Some of these faults, namely, those which are met with in the Indwe area, have already been referred to.

Besides the Glen Grey sheet, there are numerous other sheet-like intrusions, some great and others small, many of which are only offshoots from it. For example, we have the tracts just south-west of Dordrecht, between Dordrecht and Sterkstroom, and to the north-west of the latter place.

Petrography.—Throughout the whole of this area the dolerite is the usual typical ophitic rock, rather coarse-grained in character; this is especially the case with the Glen Grey sheet.

In several places there are deviations from the normal type.

In Bushman's Hoek, at the old homestead, is a great mass of light grey dolerite, in which the ferro-magnesian mineral is in the form of long needle-shaped crystals. A thin section (1,336) shows these to be augites, which are now altered to yellowish serpentine; the rest of the rock consists of plagioclase felspars, with a fair amount of interstitial quartz.

At the Tarka border, on the main road from Sterkstroom to Tarkastad, there is a somewhat different rock. The section (1,334) shows an intimate intergrowth of pale brownish augite and a pale green hornblende, large crystals of plagioclase felspar, much magnetite, and a very large amount of quartz, usually forming a micrographic intergrowth with felspar. An acid vein in this sheet (1,335) shows almost entirely quartz and micropegmatite; felspar into which quartz does not penetrate is quite rare. The rock may be termed a granophyre.

These acid veins are by no means infrequent; one, six inches wide, from a point four miles south of Lehman's Drift Siding, is composed chiefly of granulitic quartz and felspar (1,326). Another from Fincham's Nek, six miles south of Queenstown, contains dark green hornblende, and is very rich in micropegmatite (1,327).

Dykes.—The second class of intrusions, namely dykes, are extremely abundant. Though usually from 12 to 30 feet wide, they often run in straight lines for very many miles. As in the adjoining areas, so also here, the course of these dykes is most commonly either north-east or north-west.

In the coal-workings at Indwe there are several peculiar dykes. In the Byrne mine there is an intrusion which ends bluntly in the middle of the seam, the coals and shales being arched upwards to a small extent over the termination of the dyke. The dolerite is fine grained, and has a dark glassy base (1,315).

In the Dugmore mine there is an eighteen-inch dyke, with a termination that is semicircular in transverse section. It strikes east and west, and pitches rapidly eastwards, so that in a short

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distance it disappears below the floor of the workings. The shale and coal overlying the top of the dyke are arched upwards for a short distance.

Close to it there is another remarkable dyke, which is now in the condition known as "white trap." It is seen only in the roof, and can be traced for a short distance in the workings by the downward bulge it has produced.

A small outcrop of acid rock was met with in the ward of Lante in Glen Grey, which both in character and mode of occurrence differs from the usual type of intrusion.

The road to Bengu winds round a spur, crowned with a massive sandstone bed, which forms a rude horseshoe, the depression in the centre being occupied by friable sandstone and mudstone and by the igneous rock. The latter forms a small isolated patch, not more than 40 feet across, is light grey in colour and vesicular, and in places contains fragments of dolerite.

In section (1,328) it shows a fine-grained mass of quartz and felspar, with patches of chlorite, and crystals of epidote and magnetite. The vesicles are not sharply defined from the ground mass, and are filled with quartz, aggregates of chlorite with rudely hexagonal outlines, and large clear crystals of yellowish epidote.

The rock seems to form a plug-like mass.

Later Intrusions.—In a few places a second and later intrusion has followed the Karroo dolerite, either along the same path or along an entirely new fracture. In the former case we get a composite sill or dyke, and the best example of this is one that occurs on the railway between Sterkstroom and Penhoek (on the farm Gretna).

The earlier intrusion is a thick dolerite sheet—an extension of the Andriesberg mass—which is decomposed to a coarse friable sand and is quarried for ballast. The sheet is at first horizontal, and then dips eastwards at an angle of about 25 degrees. The second intrusion has taken place between the upper surface of the older one and the overlying sedimentary material, and is dark, solid, and fine-grained. For some distance these two intrusions can be distinguished in the field by their differences in weathering.

Close to Birds' River Siding there is a similar double intrusion; the later dolerite is hard, weathers red-brown in colour, and caps several flat-topped kopjes, formed of decomposed coarse-grained dolerite. In one of these, a little west of the Siding, a tongue fro mthe overlying sheet penetrates irregularly into the lower intrusion.

Outside this area similar composite sills have also been noticed; for example one occurs along the railway about a mile south of Stormberg Junction.

The second class of later intrusives forms dykes cutting through the earlier dolerites.

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South of Indwe, between the westernmost and the middle kopje, is such a one, about 20 feet in width, cutting through a thick sheet of coarse ophitic dolerite. The dyke is a beautifully porphyritic rock, with a very fine cryptocrystalline groundmass (1,317), shows a chilled selvage, and is rudely columnar, with the columns arranged normally to the sides. The best example, however, is met with at Birds' River Siding. On Stafelbergs Vley it cuts through the complex of igneous and sedimentary material (described elsewhere in this report), and forms a wall of horizontal prisms, which projects above the surface of the earlier intrusion, to a height of twelve feet in places. A thin section (1,332) shows a felted aggregate of felspar and augite prisms, set in a deep brown glassy base.

It was only followed to the summit of the Stormberg watershed, but from Dunn's Map it extends for many miles further to the north-west. In the opposite direction, it can be traced down the Birds' River, and cuts through the dolerite masses of the Glen Grey border. It is very probable that the prominent dyke which runs from Tsembeyi through to the ward of Bengu is the extension of this intrusion.

A nearly parallel intrusion, usually less than a mile distant, accompanies it on its north-west side, starting from Tsembeyi, and crossing into the Transkei at Southeyville.

Both of these dykes pass through the town of Lady Frere, while to the north-west, they cut right through the towering mass of Mount Arthur. This mountain is capped with a thick dolerite sheet, and the course of these intrusive dykes is marked by deep clefts. A similar feature is noticeable in the dolerite cap on the mountain Thaba Mtheku.

VII. Superficial Deposits.

Over most of this area the soil is thin, but in some of the basins and along many of the rivers there are flats of very fertile soil. A very good example is a well-cultivated flat not many miles east of Lady Frere, also the stretch of ground between Bolotwa and St. Marks. The mudstones of the Burghersdorp beds readily crumble away, and form a stiff soil, which is more fertile than that derived from the disintegration of the Molteno beds. The complete decomposition of many of the dolerite dykes and sheets as a rule increases the fertility.

In the west and north-west portions of Queenstown and in Tarka there are large tracts of nearly flat country, over which there is a deposit of calcareous tufa, extremely hard and usually covered with a thin sandy soil. This deposit is often from four to six feet in depth, and may pass into a conglomerate by the cementing of waterworn boulders of sandstone, flinty shale, and dolerite with a white limestone, which is often of remarkable purity.

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Bones have been found in these recent deposits, but never those of any extinct forms.

Ironstone gravels occur in places, but never form beds of any depth or lateral extent.

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GEOLOGICAL SURVEY

OF

PARTS OF HAY AND PRIESKA, WITH SOME NOTES ON HERBERT AND BARKLY WEST.

BY

A. W. ROGERS

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GEOLOGICAL SURVEY OF PARTS OF HAY AND PRIESKA, WITH SOME NOTES ON HERBERT AND BARKLY WEST.

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Introduction.

The area described in this report lies between the Vaal River on the east and the Kalahari on the west; it is limited by the Vryburg southern boundary on the north and the Orange River on the south, and a small area near Omdraai Vley, in Prieska, is also mentioned.

The country between the Vaal River and the western side of the Kaap Plateau was only traversed once, so it is not dealt with at length.

The Vaal River runs in a south-westerly direction to join the Orange River through a somewhat featureless country, which rises gradually from the right bank to the foot of the Campbell Rand or Kaap Plateau. The escarpment which limits this plateau on the east trends at first north-eastwards from the Orange River, and then north-north-east for about 160 miles; it comes to an end near Vryburg, where the boundary of the limestone and dolomite which form the plateau turns westwards. In the area we are now concerned with the highest part of the plateau lies about 600 feet above the lower ground to the east, though the precipitous escarpment is not more than half that height.

The surface of the plateau slopes gradually towards the western limit formed by the Asbestos Mountains, at the foot of which the village of Griqua Town is situated. The so-called Asbestos Mountains are really a range of rather flat-topped hills, cut into by the valleys of many tributaries of the Orange River, some of which rise in the country behind and cut through the range. These hills rarely exceed 700 feet in height above the Orange River at Prieska. The trend of the Asbestos range is parallel to the Campbell escarpment, and the range is about twenty-five miles distant from the latter.

West of these hills there is a tract of hilly country, about thirty-six miles wide, bounded on the west by the Langebergen. This hilly country becomes more and more sandy towards the Langeberg, which rises to a height of about 1,600 feet above the valley to the east. From the top of the Langeberg, one looks

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westwards far across the Kalahari, the general sandy surface of which is broken by the serrated ranges of Scheurberg and Inkruip. The Langebergen themselves have remarkably rounded summits, without any sharp peaks, though in the subordinate range east of Andries Fontein, where thick belts of shale are intercalated with the quartzites, the latter make a few prominent ridges.

The average trend of the Langebergen is north-north-east, though they are really an arc with a radius of about 105 miles round a centre some 30 miles north-north-west of Upington. Owing to this arc arrangement, the extreme southern end of the range (Ezel Rand, in Prieska) has a north-easterly strike; the middle portion trends north-north-east,and the northern part more nearly north and south.

The formations that appear at the surface in this district are:—

Recent and Superficial Deposits.—Sands, gravels, alluvium, calcareous tufa.

(Great unconformity.)

Dwyka Series.—Glacial boulder beds, gravels and shales.

(Great unconformity.)

Matsap Series (probably Waterberg Sandstone).—Chiefly quartzites and thin bands of pebbles.

(Great unconformity.)

Ongeluk Series.—Volcanic lavas, breccias, and tuffs, with a few cherty layers.

Griqua Town Series (Pretoria Beds of the Transvaal).—Ferruginous jaspers, banded magnetic rocks, sandstones, shales, cherts, thin limestones, and a glacial boulder bed near the top.

Campbell Rand Series (Dolomites of the Transvaal).—Limestones and dolomites, cherts and shales.

Black Reef Series.—Quartzites, flagstones, pebble beds.

(Unconformity ?)

Pniel Series (Ventersdorp Beds).—Volcanic lavas, breccias, tuffs.

(Unconformity ?)

Kheis Series.—Quartzites, mica schist.

There are also some intrusive rocks, diabases and very basic altered rocks.

The best account of the structure of this country given by the early explorers is certainly that of W. J. Burchell, though Lichtenstein mentions the occurrence of certain rocks and took to Europe the specimens of crocidolite and allied rocks described by Klaproth. Burchell says:—" The whole substratum of this part [Klaar Water, now Griqua Town] of the country, for many

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leagues northward and eastward, is a hard limestone rock of primitive formation; and on this rest the laminated argillaceous mountains."[1] He also describes asbestos and a mineral allied to "cat's eye."[2] A slight account of the rocks in the south-eastern part of Hay is given by R. Moffat,[3] who recorded the occurrence of sandstone in the Scheurbergen and Langebergen, and the fact that the rocks of the latter lie upon "ribbon-schist" (Griqua Town beds) and "mountain limestone south-west of Kuruman."

The first thorough geological description is that of G. W. Stow.[4] The present survey has led me to take other views than Stow's of several features, of which the most important are:—(1) The nature of the unconformity seen in the escarpment of the Kaap Plateau at Leij Fontein; (2) the relation of the Ongeluk volcanic series to the Griqua Town beds; (3) the nature of the Blink Klip breccia; and (4) the relation of his "Rooi Kopje" beds and "irregularly bedded jaspery rocks near Matsap." As to the unconformity at Leij Fontein, it appears to be a local break in the Campbell Rand formation; the Ongeluk volcanic rocks lie conformably upon the Griqua Town beds, and are separated from the Pniel lavas and breccias by the whole thickness of the Black Reef, Campbell Rand, and Griqua Town beds; the Blink Klip breccia is not an ordinary detrital rock, but it seems to have been formed by the collapse of Griqua Town beds, under the influence of gravity, and, perhaps, earth-movements, into hollows dissolved out of the underlying limestone; and the Rooi Kopje and irregularly bedded jaspers are parts of the Griqua Town beds, not separate formations.

There will be found below many references to Stow's work, but to have pointed out on every occasion agreement with or difference from his conclusions on matters of smaller importance would have unduly increased the length of this report.

The area dealt with includes some 4,000 square miles, which Stow covered in about two months; there are gaps in this area which I could not traverse last season, but even allowing for these, the three months (excluding days spent in fitting out and packing up, etc.) of mine were a short time for the area. For the time taken, Stow's results are remarkable, and they materially lightened the work of the present survey.

No further geological work seems to have been done in Hay till Mr. E. J. Dunn went there in 1885, for the purpose of "visiting the localities where crocidolite exists, ... particulars of

[1] "Travels in South Africa," 1822. Vol. I., p. 359.

[2] *Ibid.* p. 333.

[3] "Report of a Survey of a Portion of the Orange River, Eastward of Little Namaqualand," by R. Moffat, Esq., Government Land Surveyor, Cape Town, 1858. (G. 1—'58.)

[4] "Geological Notes upon Griqualand West," Q. J. G. S. XXX., 581-680, also "Cape Monthly Magazine," 1872, pp. 65-78.

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the geological formation in which the material occurs, and of procuring additional specimens of this mineral for the purpose of the Colonial and Indian Exhibition."[1] The results of this journey of Mr. Dunn's are shown in his "Geological Sketch Map of South Africa," Melbourne, 1887, in which all the sedimentary rocks from the eastern side of the Campbell Rand to the Kalahari are placed together in the "Lydenburg beds," and both the Pniel volcanic rocks and the Ongeluk volcanic rocks are called "Diabase, etc., later than the Lydenburg beds." Though as regards the Ongeluk rocks Dunn's map is an improvement upon Stow's, the inclusion of the lavas and breccias of the Vaal River valley in a group younger than the Griqua Town beds is not correct, nor is it an advantage to place together in one great group the Campbell Rand limestones, the Griqua Town beds, and the great quartzite group (Matsap beds) of the Langebergen in Hay and Ezel Rand in Prieska.

Since 1887 no map or memoir on the Hay Division, based upon further exploration, has appeared, but in 1899 the Cape Survey mapped the adjacent district of Prieska, and the results, so far as they concern the Campbell Rand, Griqua Town, and Matsap groups, upheld Stow's classification in Hay. The amygdaloidal diabase and associated compact rocks which occur mainly below the quartzites at the base of the limestones in the Doornberg area were at that time regarded as intrusive masses, but partly owing to work done in the Transvaal and near Vryburg, and an examination of the rocks under the microscope made since the 1899 Report was written, I have now no doubt that the Prieska amygdaloids are ordinary volcanic rocks, and represent the Ventersdorp beds of Hatch and the Pniel lavas and breccias. A recent examination of the T'Kuip hills confirmed this change of opinion, but there is now a difficulty in the arrangement of the lavas near Ezel Rand, which can only be solved by another visit to that locality, or possibly by a survey of the country on the north bank of the Orange River, a work which will probably be undertaken during the coming season.

As a whole, the rocks in the Hay Division are much less disturbed than the same rocks in Prieska. From the Kaap Plateau westwards as far as Matsap, the Campbell Rand, Griqua Town, and Ongeluk groups lie at low angles. The general trend is about N.N.E. The country between the Vaal River and the western limit of the Asbestos Mountains is probably the western or north-western limb of a very broad anticline, the axis of which is somewhere near the course taken by the Vaal, though the eastern or south-eastern limb is concealed under the Karroo formation as far up the river as the neighbourhood of

[1] Parliamentary Report. G. 8—'86. Cape Town, 1886, p. 3. A list of specimens collected will be found in the Catalogue of the Colonial and Indian Exhibition, London, 1886.

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Klerksdorp in the Transvaal.[1] The north-western limb of this wide anticline meets with the north-west trending rocks of the Doornberg range at Kliphuis, Enkelde Wilgeboom, and Buis Vley, where there is a small but broad dome-shaped mass of Campbell Rand beds, forming an inlier amongst the Griqua Town series. Below Enkelde Wilgeboom the Orange River runs more or less along the strike of the Griqua Town and Campbell Rand beds, where they have the Doornberg trend, as far as the poort through the Langeberg group of hills. It thus happens that at the localities nearest the Orange River the rocks in Hay, east of Langeberg, have the north-westerly strike of the Doornberg area; but further north, they turn parallel to the Campbell Rand and Asbestos Mountains.

Gentle synclinal folds with the prevailing N.N.E. trend bring in the Ongeluk series in the basins of Ongeluk-Witwater, Juanana, Abram's Dam, Paarde Vley, and Vlak Fontein, but on the western side of the Lucas Dam syncline the beds are overturned, so that the Ongeluk series dips under the Griqua Town beds, and the latter also dip westward towards the Langeberg, but the Campbell Rand group is not exposed west of Lucas Dam. The Langebergen are made of much bent Matsap beds, but whether on their eastern flank they merely lie unconformably upon the Griqua Town beds, as they do at their southern end on Witberg and at the south end of the Matsap outlier, or whether this limit is complicated by a thrust, is not yet known. In any case, the great disturbance of the Griqua Town beds near Lucas Dam is probably to be attributed to the earth-movements that affected the Matsap beds of the Langeberg. The previous disturbances that gave the Doornberg rocks their north-westerly trend are older than the Langeberg earth-movements, for the Matsap beds of Ezel Rand terminate the older rocks, and are only affected by the later disturbances that puckered up the Langebergen.

Of the later history of this area little can be learnt from the district itself; there are outliers of the Dwyka known along the southern edge, and there may be others under the sand further north, but the gap between the Matsap beds and the Dwyka, and the immense interval between Dwyka times and those represented by the high-level gravels, are not bridged by any rocks in Hay.

It should be remarked that in all cases of faulting where the presence and throw of the fault were ascertainable, excepting the second fault near Paling, the downthrown side lay on the east; no east and west faults of any importance were noticed.

[1] See the map attached to Molengraaff's "Geology of the Transvaal," Edinburgh and Johannesburg, 1904, and Pl. I in Hatch and Corstorphine's "Geology of South Africa," London, 1905.

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KHEIS SERIES?

On the farms O. 254, O. 259, O. 260, and O. 262, on the western side of the Langeberg, and separated from that range by sand-covered ground, there is a group of ridges trending S. 4° E.[1] The ridges are made of quartzites, with vertical or almost vertical dips, and the strike is parallel to the trend of the hills, viz., S. 4° E. There is a considerable divergence between the strike of these rocks and that of the quartzites of the Langeberg in their neighbourhood; for the rocks of the Langeberg strike S. 20°-25° W. The dip of the latter (Matsap beds) is towards E.S.E., along the western side of the range near Pad Kloof, though as the beds are much folded, the dip soon becomes reversed.

Where I crossed the ridges, along a line north-west of Pad Kloof, and about nine miles south of Witsands, there are three prominent ridges of quartzite, with parallel depressions filled with reddish sand, between them. The hills rise about 250 feet above the sand on the east side.

On the eastern side there are first massive quartzites, with a very high westerly dip. The colour is grey and pink. Some beds have numerous small dull white and pink grains in them, evidently weathered felspar. Magnetite is scattered through the rock, occasionally in sufficient quantity to give rise to a dark grey layer parallel to the bedding planes. Pyrites is present in parts of the rock, and is distributed irregularly through it.

Irregular false-bedding is prominent in some beds.

Small quartz pebbles are to be found in the rock, though they are much less abundant than the pebbles in the Matsap beds. These massive beds are followed to the west by thinner-bedded quartzites, which are separated by a sandy depression from the middle ridge, also made of thin quartzites, dipping vertically; the second depression is similar to the first, and the third ridge to the other two ridges. No outcrops were seen in the depressions, but there were pieces of quartz-schist lying in the sand of such size and form that they probably come from rocks concealed by the sand. The quartz-schist is made of quartz and sericite, and resembles rocks that occur in the hills near Brakbosch Poort, in Prieska.

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[1] All bearings in this Report, as in previous publications of the Geologica Commission, are corrected for declination. In comparing any of these figures with those of Stow in Q. J. G. S., vol. XXX., it must be remembered that the bearings given in his text were not so corrected, for they do not tally with the strikes, etc., as laid down on the map attached to the paper. A correction of 25°—30° west will bring his bearings into agreement with his map and with the majority of the observations made by me. To correct Stows bearings they must be turned round about 25°—30° in the direction opposite to that taken by the hands of a watch; *e.g.* north would be north 30° west, and south-east would be east 15° south; etc.

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With the little information at present available, there is nothing further to be said in regard to the relationship of this group of rocks to the Matsap beds, than that they are almost certainly older than the latter. The absence of the jasper pebbles so frequently seen in the Matsap beds is striking, especially as these pebbles are rather more abundant than usual in the neighbourhood of Pad Kloof.

The Pniel Volcanic Series (Ventersdorp Beds).

The lowest beds seen on the surface between Barkly West and the Langeberg are the lavas and breccias in the valley of the Vaal River; these volcanic rocks undoubtedly underlie the Campbell Rand group and also the quartzites and gritty rocks on N.W. 4 (Herbert), which are referred to the Black Reef series. They consist of compact and amygdaloidal lavas, some of which are distinctly porphyritic, coarse and fine breccias, and tuffs. They are greenish blue in colour as a whole, but the more acid varieties are paler than others, which are evidently more basic.

These rocks have not been examined microscopically, but they have a general resemblance to the lavas and breccias which rest directly on the granite at T'Kuip near Omdraai Vley in Prieska, and which are described below.

It is interesting to note that the lavas and sedimentary rocks lying nearly horizontally below the Karroo formation at Kimberley have been pierced by a shaft at De Beers' mine, and that they rest upon a coarse granite at a depth of about 1,920 feet from the surface.

The T'Kuip Hills in Prieska.

Owing to a delay in travelling from Omdraai Vley to Prieska, I was able to spend a day on the T'Kuip Hills. This is the locality referred to in the Annual Report for 1899, p. 85, where it is stated that the amygdaloids send a long dyke-like intrusion through the granite of T'Kuip. I had time to make an examination of the south and central parts of the range, which is about eight miles long.

It is true that diabase dykes very similar in nature to the more compact lava of the volcanic group traverse the granite and gneiss, but the long extension mentioned in the Report for 1899 is really the basal portion of the volcanic group, overlain by a thick group of acid porphyritic lavas.

The granite rocks occupy the lower slopes of the hills on their eastern side; they are chiefly reddish gneissose rocks, in which biotite is abundant, but white fine-grained muscovite gneiss is also present, and there is much coarse pegmatite and massive granite in lenticular layers parallel to the foliation of the gneiss. The foliation planes run nearly vertically between north and

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N. 20° W., the strike varies within short distances. A dyke of compact diabase 20 feet in width runs in a general north-westerly direction through the gneiss towards the volcanic group about 2½ miles north of the south end of the hills.

At the base there is a thick band of coarse breccias, made up largely of material derived from granite mixed with a greenish epidotic substance, probably of volcanic origin. Interbedded with the breccias are layers of very fine-grained green tuff and amygdaloidal lavas. The whole thickness of interstratified lavas, tuffs, and breccias at this locality is about 400 feet, and the highest beds are dark, coarse grits, containing occasional angular and subangular fragments of granite, quartzite, and vein quartz up to six inches in length.

These well-bedded rocks are succeeded by a great thickness of acid porphyritic lavas, which weather with a yellowish-white crust about 1-10th inch thick. In a hand-specimen these rocks have a close resemblance to some of the Beer Vley lavas. The matrix is blue-grey in colour and very compact; it contains porphyritic crystals of quartz and felspar, and a few amygdales of chalcedony. These acid lavas form the highest part of the T'Kuip hills. Their thickness must be very considerable, at least 500 feet.

The south end of the hills is made of basic lavas, which are much more amygdaloidal than the acid group above the breccias and tuffs. The basic rocks rest upon the gneiss of the eastern slope, and apparently underlie the breccias and tuffs

On the low ground west of the hills there are two outcrops of compact fine-grained breccia on the line of strike of the breccia band of the hills. These were the only outcrops I could find between the hills and Omdraai Vley, except a dyke of dolerite of the Karroo type. The low ground is sandy, and is strewn with lumps of surface limestone, such as underlies the soil over large tracts of country in the north of the Colony. There are also many boulders, which have weathered out from the Dwyka glacial beds, scattered over the flats. Their origin is proved by more or less well-preserved scratches or by their general shape; they are of various kinds of rock, but on T'Kuip and Omdraai Vley the majority are from the volcanic group, granite and crystalline limestone. The glacial boulders are also frequently seen in the valleys in the T'Kuip hills, so these hills have only been denuded of their covering of Dwyka within comparatively recent times.

Though the quartzites of the Black Reef series do not occur, or have not yet been found in the immediate neighbourhood, there can be little doubt that these volcanic rocks underlie the limestone (Campbell Rand group) which crops out in the Becha hills about three miles north of T'Kuip, and the quartzites appear on Zoet Vley, eight miles west of the T'Kuip hills. All these occurrences are inliers amongst the Dwyka series.

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Black Reef Series?

On the east side of the Kaap Plateau or Campbell Rand there is a hill range on Mr. Shaw's farm, N.W. 4 (Herbert), made of quartzites, grits, and greenish flaggy beds, which dip at an angle of 5° towards N. 20° E. They are over 200 feet thick. Owing to the necessity of travelling through the night to reach the river at this place, on my return journey from the Hay district, I could not follow the connection of these quartzites and some quartzites in the Sogo location ground seen the previous day, but they are probably part of the same group, for they both underlie the dark shales and the limestones of the Kaap Plateau, and are above at least the greater part of the volcanic rocks of the Vaal valley.

The Sogo quartzites are not so well exposed, but they appear to be intercalated amongst the volcanic beds of that locality. On N.W. 4 some 400 feet of volcanic beds are very well exposed, and they lie under the quartzites and grits; a small tributary of the Vaal has cut a valley along the junction of the sedimentary and volcanic beds, and the actual passage is not seen on that farm, but it may be a conformable one, for the dips of the two groups are about the same in direction and amount.

Between the Campbell Town kloof and the Sogo location the ground where the Black Reef series should crop out, if present, is covered with the Dwyka series and recent alluvium and gravels.

Until some work has been done in the Vaal River valley it will not be possible to decide definitely upon the relationship of these quartzites. Drs. Hatch and Corstorphine[1] place the quartzites interbedded with the volcanic rocks under Kimberley in their Ventersdorp group, and it is likely that the Kimberley sections are typical of a wide area westwards, for the rocks in that district lie at low angles.

The Campbell Rand Series.

This name was used by Stow[2] for the "siliceous and crystalline limestones" of the Campbell Rand, which clearly indicates the group of rocks referred to. In the Annual Report for 1899 there is a description of part of the Prieska Division, in which the term Doornberg series is used to include both the Griqua Town and Campbell Rand groups; while the Campbell Rand group was held to include not only the dolomitic limestones, but also the quartzites below these limestones, because there was no break in the succession.

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[1] Geology of South Africa, 1905, p. 152.
[2] Loc. cit. p. 613 and legend of the map, Pl. XXXV.

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There is no longer any use for the name Doornberg series, as the whole group is admitted generally to be an extension of the Transvaal system of Molengraaff[1] or Potchefstroom system of Hatch and Corstorphine[2].

The quartzites and other rocks of sedimentary origin which lie below the limestones of the Kaap Plateau can best be put into the Black Reef series, and the Campbell Rand series limited to the limestones, dolomites, and associated cherts, shales, and quartzites. This name will be used here in preference to "The Dolomite Series" as the Transvaal equivalents are called, on account of the priority of Stow's term and the fact that much of the rock is not dolomite, but limestone or a magnesian limestone with too little magnesium carbonate in it to be called dolomite.

The most characteristic rock in the series is the limestone. Many specimens collected are soluble in cold dilute hydrochloric acid, but there appear to be all varieties between these and dolomites which are not affected by the acid.

The usual colour of the rock is bluish grey, and the structure is crystalline. Near the intrusive dykes of diabase and more basic rocks the limestone is altered considerably; the diabase has turned the rock into white crystalline limestone, in which the colouring matter of the rock is gathered together in small black specks, and the more basic rocks have brought about greater alteration, which will be described in connection with those intrusions.

The cherts are grey or black, sometimes spotted with lighter patches, of which the origin is not yet known. Thin sections of these rocks have not yet been prepared; thin sections of cherts from the Campbell Rand beds in Prieska collected in 1899 show no organic structures.

The cherts are chiefly found to be interbedded with the limestones, either regularly or in nodular masses; they also occur in joints, usually perpendicularly to the bed planes.

There are three areas in our district where the Campbell Rand beds appear at the surface. First, and most important, is the Kaap Plateau or Campbell Rand; secondly a large part of the Field-cornetcy of Blink Klip, in the north-west of Hay; thirdly a small but interesting area cut through by the Orange River on O. 346, Wilgebooms Dam, Enkelde Wilgeboom, and Kliphuis.

(1) *The Kaap Plateau.*

The Kaap Plateau forms the eastern part of the Hay Division, the boundary of which coincides with the edge of the Plateau for some miles south of the Campbell Town kloof. In this neighbourhood the Plateau is about 24 miles wide. The

[1] "Geology of the Transvaal," 1904.
[2] "Geology of South Africa," 1905.

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surface slopes very gradually towards the east, where the feature comes to an end at the foot of the Asbestos Mountains. On the East its edge forms a fine escarpment, overlooking the valley of the Vaal River.

During the past year the only work in this area was done during a journey from Griqua Town northwards to Kogel Been, and thence in an east-south-east direction to Campbell.

A visit was made to Leij Fontein, south of Campbell, with the object of seeing the section described by Stow,[1] where he found an unconformity at the base of the limestones, and rocks, which he took to be very much older, perhaps the equivalents of the Kheis beds, lying below it. I found an unconformity very well displayed in two kloofs south of Leij Fontein house and on the face of the escarpment. The lower beds, *i.e.*, those below the unconformity, consist of quartzites, limestones, cherts, and slightly micaceous shales. They dip at angles of from 10° to 35° in a westerly direction, between W. 10° S. and W. 14° N. I found no rocks that could be called schistose in the sense that the mica-schists rock of the Kheis series are so named. The micaceous shales are thinly laminated, but the mica flakes are not particularly abundant. The quartzites are rather glassy-looking rocks, with large quartz grains; they resemble some of the quartzites below the limestones west of the Doornberg in Prieska. Calcareous quartzites are also present, and in some of the thick limestones there are lenticular patches of quartzite. The limestones and cherts below the unconformity are not visibly different from those above; both on weathered and fresh surfaces they have the same appearance as many beds above. The unconformity is very sharply marked, and at several places the actual junction can be examined. There is no breccia or conglomerate at the base of the upper group, nor is there any sign of disturbance or slickensiding to indicate a thrust plane. The upper group of beds also has a lower dip than those below; the general direction of dip is towards W.N.W., but the dip varies both in amount and direction.

From the exposed part of the unconformity it is evident that some 300 feet of rock, or even more, were removed from the northern end of the section; and as the dip of the upper beds carries the unconformity below the surface south of Leij Fontein, the real value of the discordance is not ascertainable. The outcrop of the unconformity passes on to the surface of the plateau behind Leij Fontein, and I did not find it in the Campbell Town Ravine, where the rocks exposed on the sides of the kloof probably lie below it, if it persists so far.

North of the Campbell Ravine dark shales are frequently seen interbedded with the limestones and cherts. These shales

[1] Stow, *Loc. cit.* p. 619.

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were examined at intervals from Leij Fontein to Clearwater, and they appear to be suitable rocks for the preservation of fossils, but nothing was found in them.

Shales were rarely seen on the Plateau itself, though it is only in artificial sections that they can be exposed on such a plain.

The part of the plateau traversed by me is singularly featureless; no stream beds of any note were met with until the eastern escarpment was approached; a few small and shallow pans, waterless at the time of my journey, were the only depressions seen.

Towards the western edge of the plain there are a few small kopjes, on which the bedding of the limstones and cherts is well displayed. One of these kopjes has a remarkably regular step-form, like that described by Stow[1] from near Daniel's Kuil. The rock is jointed vertically and the bed planes lie horizontally; the limestone breaks and yields to solvents more readily along these planes than in other directions, so rectangular pieces are released, and the step-like form produced.

Chert is very abundant on the Plateau; it often crops out in irregularly disposed plates, which may be layers disturbed from their originally horizontal position by the removal of the enclosing rock, or they may be weathered out from more or less vertical joints. Loose fragments of chert, which must have been weathered out and left near their present positions by the solution of the limestone, are everywhere scattered over the surface. These rough pieces of chert are a certain sign of the presence of the limestone underfoot.

The dip of the Campbell Rand beds can be observed occasionally on the plateau, though in such a rock it is difficult to know that any particular outcrop, whose connection with surrounding rock is concealed, does not owe its inclination to solution of underlying beds. The wells give the best exposures. On O. 426, O. 425, and O. 41 the beds lie nearly horizontally; on Kogel Been, O. 43, and O. 38 they dip at low angles towards the Griqua Town hills (Asbestos Mountains), and the same is the case near Griqua Town. The actual junction of the limestones with the Griqua Town beds is concealed under gravels or tufaceous limestone between the south end of the Commonage at Griqua Town and Kogel Been, but there can be no doubt that the limestones pass westwards under the Griqua Town beds of the Asbestos Mountains.

(2) *The Blink Klip Field-cornetcy.*

The upper beds of the Campbell Rand group underlie a wide area in the north-west of Hay. They are brought up by a low anticline, with its axis trending about S. 25° W., and are evidently the southern end of a large limestone area in the Vryburg Division.

[1] *Loc. cit.* p. 658.

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Lithologically, the beds exposed are identical with those in the Kaap Plateau. They are best seen in the river bed which passes through Postmasburg.

On the eastern side of the area from the Barkly West boundary down to Kalk Fontein, the limestones dip at a low angle and conformably under the Griqua Town beds; the angle rarely exceeds 5°.

The southern end of the area probably lies between the Wolhaar's Kop hills and Kameel Fontein, but this ground is very much hidden under gravels.

The western side is marked by the northern continuation of the Wolhaar's Kop hills on M. 95 and M. 93. North of the last-named farm a complication is brought in by the fault on Paling, along which the Matsap beds are thrown down to the east, so that the limestones are lying against the Matsap beds of the ridge on which the north beacon of Paling stands. This limestone west of the Paling fault has only been seen at a few spots on the veld, but the abundance of tufaceous limestone in the neighbourhood shows that the beds extend further than the area shown by outcrops. Probably a second fault lies west of the limestone, for in the stream bed running west from Paling homestead the top beds of the Griqua Town series are seen between the Matsap beds and the syncline of the Ongeluk volcanic beds on Vlak Fontein. This second fault must have a westerly downthrow.

The Blink Klip breccia of Paling bounds the limestone as far as the Vryburg line, and the same rock occurs in outliers at various places in the neighbourhood. This area will be considered in more detail when the Blink Klip breccia is dealt with.

(3) *Enkelde Wilgeboom, etc.*

About five miles below Prieska village the Orange River traverses an irregular dome of limestone, which rises at a low angle from beneath the Griqua Town beds.[1] This broad anticlinal inlier lies in the angle between the Doornbergen, with their south-easterly strike, and the rocks of Hay, which strike north-north-east, at a place where the two directions of folding meet.

The Campbell Rand beds are lying at low angles, but their dip is rather disturbed, for it frequently changes. The uppermost 200 feet or so of the series are alone seen on the north of the river. Chert is not so abundant in the exposed sections as in the same rocks on the east and north of Hay.

The most interesting feature in this inlier is the passage upwards into the Griqua Town beds, which is very well exposed on the steep slopes on Klip Huis, below the trenches from which crocidolite is obtained. Beds of magnetic jaspers are inter-

[1] That part of the area on the south side of the river is mentioned on p. 78 of Ann. Rep. Geol. Comm. for 1899.

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bedded with the blue crystalline limestones towards their upper limit, and these jaspers are in no way different from the similar rocks which lie above the limestones. There is no sign of any discordance or any subsequent disturbance of the strata along the exposed part of the junction on Klip Huis. The top of the Campbell Rand group was taken at the top of a thin layer of a peculiarly light white and pink rock about 18 inches thick. This is a peculiar rock; it is very light, owing partly at least to the minute pores in it; it appears to be a hydrous aluminous silicate, such as kaolinite, as it contains alumina, silica, and water, and the powder under the microscope is seen to consist of very minute flaky pieces of a transparent mineral, with weak double refraction.

Thickness of the Campbell Rand Group in Hay.

No estimate with an approach to closeness can be made of the thickness of this group. The width of the principal area of the Kaap Plateau, the present uncertainty as to the position of the base there, and of the dips on the Plateau, prevent the measurements having any value. In Prieska[1] the group was found to be about 5,000 feet thick, and it may be as thick in Hay.

THE GRIQUA TOWN SERIES.

This group of rocks occupies a very wide area in Hay. It forms the low range of hills called the Asbestos Mountains, and a further wide area south of the great syncline of Ongeluk and Witwater; west of this syncline it is more important than any other group until the Langeberg is reached.

On lithological and stratigraphical grounds those rocks called by Stow Blink Klip breccia, and those mentioned as "the red jaspers of the Rooy Kopjes," and "irregularly bedded jaspery rocks near the Matsap hills," are here included in the Griqua Town series.

Description of the Rocks.

The characteristic rock of this group is a very hard siliceous rock, with more or less magnetite in it. The colour varies greatly, pale yellow, brown, red, and black are the most usual, but the differently coloured rocks do not often occur at the same place. The colours are due to the state of the iron; where the iron is all in the form of magnetite the rock is black; haematite and limonite colour the red and the yellow and brown rocks. These rocks are usually called jaspers. No thin sections have yet been cut from the Hay rocks belonging to this group, but as the same beds occur in Prieska, and sections from them are

[1] Ann. Rep. Geol. Comm. 1899, p. 80.

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available, the characters can be described from the Prieska specimens.[1]

The jaspers are usually banded; the layers of differently coloured rock vary from the thinnest visible streak up to a couple of inches in thickness. The black magnetite layers are interbedded with yellow, brown, or red jasper. Rarely the red rock is interbedded with the yellow or brown.

An average specimen of the brown jaspers (463, T'Dyzega, Prieska) shows under the microscope a transparent base of very minute quartz areas, just like the cherts in the Campbell Rand group, and a great quantity of brown amorphous matter, which must be hydrated oxide of iron. In the smallest particles the iron ore is transparent, and yellowish in colour. The iron ore occurs so abundantly in certain bands that they are almost opaque, but minute clear spaces are to be seen, especially under a high power, and these spaces are patches of chert. In the clearer layers the iron ore occurs in lumps with irregular boundaries and in very small flakes and spots throughout the chert. These small flakes may lie entirely within a crystalline quartz grain, or they may extend from one into another. They do not often lie between two grains.

A section from a red and black banded (472, from Nauga, Prieska) rock shows that the magnetite is confined to well-defined layers, and that it rarely occurs isolated in the red layers, though there are streaks formed by a layer of single particles running through the red rock. The magnetite is the form of irregular granules. The clear base is chert, as in the brown rock. The red layers are sharply defined, but oval or nodular patches of the red rock occur within the magnetite layers. The red colour is given to the rock by red dusty matter and extremely fine red needles. A yellowish dusty material is present in small amount.

A rock from Nauga (469 and 470, Nauga, Prieska) shows some very interesting features in addition to those characters mentioned above. The bulk of the rock is composed of magnetite and chert, but there is a fair amount of brown hydrous oxide also; with these there are two other minerals, one is a brilliant green biotite, in fair sized flakes, and the other is crocidolite, in very small crystals. The larger crocidolite crystals are big enough to measure the extinction angle on (16°-18° with the length of the prisms), and to determine the pleochroism on, violet parallel to the direction of least elasticity, which is the long axis of the crystal, and green across the prisms.

[1] The specimens selected come from the Doornbergen and not from the magnetic quartzites associated with the gneiss further west. In the 1899 Report the western outcrops are described as belonging to the Griqua Town series, but this view must be given up. The recent work of Mr. du Toit in Vryburg and Mafeking has thrown much light on the Prieska rocks, and the western outcrops of magnetic quartzites, etc. are very probably much older than the rocks of Doornberg.

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The heavy blue and green rocks associated with the crocidolite worked on Westerberg and found at the south end of the Doornberg range also occur frequently in Hay. When a piece of the blue rock is crushed and the powder examined under a high power, the smaller fragments are seen to have a fibrous structure and the same optical properties as crocidolite. The green rock has less crocidolite in it than the blue, and it is largely made of a greenish mineral, which has not been determined. The very dense dark blue rock, which is often found with a highly polished black exterior, and which is more conspicuous in the form of pebbles in the Orange River gravels and fragments lying on the surface of the ground far from outcrops of similar materials,[1] gives a powder entirely formed of small crocidolite fibres. The specific gravity of two specimens of the blue rock is 3·30 and 3·27. This heavy blue rock is evidently the same as that collected by Lichtenstein on the Orange River and analysed by Klaproth,[2] who gives the following figures:—

Silica...	50
Iron protoxide	40·5
Lime...	1·5
Soda...	5
Water	3
Specific gravity	3·200

He called the rock "Blau-eisenstein."

Hausmann[2] distinguished between an earthy and an asbestos-like variety of the mineral, which he named Krokydolith. The two varieties were analysed by Stromeyer[3]:—

	Earthy variety.	Asbestos-like variety.
Silica...	51·64	50·81
Iron protoxide	34·38	33·88
Manganese oxide ...	·02	0·17
Magnesia...	2·64	2·32
Lime	·05	0·02
Soda	7·11	7·03
Water...	4·01	5·58

The earthy variety is probably the same kind of rock as that collected by Lichtenstein, though not identical with it. The asbestos-like variety is certainly the mineral that is now being worked in Prieska and Hay.

[1] Pieces of this rock picked up on the veld are often thought to be meteorites by the farmers. One man assured me he saw a stone fall about 500 yards away, and on digging at the spot disturbed he got the lump of crocidolite, which he gave me.

[2] Klaproth, M. H. "Beitrage zur chemischen kenntniss der Mineral Körper," 1815. Vol. 6, p. 237.

[3] Quoted by Hintze, "Mineralogie," p. 1265; Gött. gel. Anz. 1831, p. 1585; Stromeyer, Pogg. Ann. 1831, 23, p. 153.

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The heavy green and blue rocks are, from their mode of occurrence, certainly sedimentary rocks which have undergone great mineralogical alteration since their deposition. They are interbedded with jaspers, and also with strata that are more like normal sedimentary rocks. Whether the blue beds are made of the debris from lavas, either in the form of fine tuff or riverborne detritus, or whether they were deposited under other conditions, is not definitely known; the occurrence, however, of ferruginous sandstones and calcareous rocks in the upper part of the Griqua Town series on certain farms in Hay, while elsewhere the beds on the same horizon are the heavy green and blue rocks or red and brown jaspers, makes it probable that further investigations will prove the derivation of the crocidolite rocks from ferruginous sediments.

The hard yellow alteration product of crocidolite was also taken to Europe by Lichtenstein and analysed by Klaproth, who called it "Faserquarz."

He gives the figures:—

Silica...	98·50
Oxide of iron	1·50

Several later analyses are given by Dana in his "System of Mineralogy," 1894, pp. 400 and 401, which show slightly less silica and a larger quantity of iron oxide (mostly the sesquioxide). Dana also gives an analysis by Hepburn of the soft yellow mineral called griqualandite, an intermediate stage between crocidolite and the very siliceous fibrous quartz mentioned above. Hepburn's analysis gave:—

SiO_2	56·75
Fe_2O_3	37·64
FeO	1·09
MgO	·10
H_2O	5·23

Griqualandite is not often met with; all the specimens I have seen come from the left bank of the Orange River, between Buis Vley and Westerberg. The Cape Asbestos Company found a fairly thick layer of it in one of their cuttings on Westerberg. Griqualandite is brittle, golden to coppery yellow in colour, and is of no use for the purposes to which asbestos is put.

The asbestiform crocidolite, or one of the series of products of oxidation and silicification derived from it, are known from almost every farm situated on the Griqua Town series in Hay, though the mineral is worked on a few farms only. During my survey work was being carried on at Klip Huis, Koegas, and Leelyk's Staat in Hay.

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These minerals occur in layers parallel to the bedding planes of the enclosing rock; where the rocks have been fractured or much bent small veins of crocidolite traverse them at an angle, and in most cases a connection between such a vein and a layer parallel to the bedding can be traced. The occurrence of the mineral in this form, the thin layers of dusty matter sometimes seen in the fibrous mineral traversing the fibres in a plane parallel to the bedding of the enclosing rock, together with the existence of beds of the earthy or compact variety, point to the development of the fibrous mineral from the compact variety in place. If this be a correct interpretation, there must be intermediate stages in existence, but the only place where I have seen an intermediate step is near Claradale (Riet Fontein or T'Aap). At this place there are roughly fibrous blue rocks, which have a general appearance of the compact variety of crocidolite, with the strongly developed cleavage in several planes, which intersect each other in one and the same direction. This blue rock consists of a greenish non-pleochroic mineral and of crocidolite, but the latter mineral has not the length of fibre or the parallelism of the asbestos. The direction taken by the incipient fibres is inclined at an angle of 30° or so to the bed planes, whereas in the asbestos this direction is perpendicular to those planes, or nearly so, and it is rarely inclined 45° from the perpendicular.

In Prieska[1] it was noticed that crocidolite (blue asbestos) occurred along with the heavy blue rock, and the oxidised and silicified varieties with the jaspers, indicating a parallel change in the two materials. In Hay, however, there are places where the blue asbestos is worked in the hardest magnetic jaspers. At Klip Huis the blue asbestos (crocidolite) occurs, together with silicified and oxidised varieties, in yellow and black magnetic jaspers. In several trenches opened up there by the Cape Asbestos Co., layers of the intensely hard yellow and blue fibrous mineral change into the soft blue form of crocidolite at a distance of two or three feet from the outcrop, and the soft mineral is obtained on a commercial scale under these conditions. It is by no means in every case that the hard variety changes thus, and the soft blue variety is more frequently obtained by following up outcrops of the same. At Kranz Fontein and at The Kloof I did not find a similar transition in the open workings, made for the purpose of obtaining the hard varieties, though some of the cuttings had been carried far enough to exhibit the change if it had taken place within the same distance as at Klip Huis.

These facts show that the change of condition is not due to reactions going on at the present time, but that the gradual passage from the hard to the soft varieties at Klip Huis is probably accidentally connected with the present surface.

[1] Ann. Rep. Geol. Comm. for 1899, p. 81.

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The change from the unoxidised to the oxidised and silicified rocks has taken place under conditions that have not yet been explained, but which are not directly connected with the disturbances which have affected the area. Both the oxidised and unoxidised—the yellow and blue—rocks show, in several areas, the effects of extensive earth-movements, and then, again, they both lie comparatively undisturbed over wide stretches of country.

The chief changes are the oxidation of the blue ferrous compounds and the addition of silica. Whether silica has been added from outside or whether it has merely travelled from certain beds in the series to others is not yet clear; it is evident, however, that the layers of yellow fibrous quartz have been enriched by nearly 50% of silicia from outside themselves.

The cherts in the Griqua Town beds are like those in the Campbell Rand series. They are particularly abundant near the top of the group. In some cases they contain octahedra of magnetite, as on Tolo.

Limestones are not frequently met with, but they occur in the hills near Rooi Laagte and at several places in the Koegas Field Cornetcy, always within 300 feet or so of the top of the series. In character they are like many of the Campbell Rand limestones, blue or grey in colour, crystalline, and they weather with the same brown irregular surface that is considered characteristic of the Dolomites of the Transvaal, and which has given that rock the name of Olifant's Klip.[1] These Griqua Town limestones are not thick, rarely over 12 inches.

On Rooi Laagte there are sandstones and shales containing calcareous matter and much iron; the latter is concentrated on each side of joint planes and along some of the bedding planes. Interbedded with the calcareous sandstones there are rocks in which silicification has taken place, but not to the same extent as in the jaspers; the iron in this rock is in the form of limonite.

The Rooi Laagte rocks are much less altered from their original condition than are the Griqua Town beds at any other locality at which I have seen them.

There is no reason to doubt that the banding, due to high content of magnitite, or to the presence of limonite or haematite, indicates the original bedding planes of the rocks. The conformity of such layers with beds of less altered rock is a conclusive proof of this point in the areas where the highly and less altered rocks occur together, and the assumption that the bands are beds or laminae in those areas where only highly altered rocks occur leads to results, as regards structure, that are in agreement with what would be expected.

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[1] This mode of weathering is found in all the crystalline limestones of Pre-Cape age known to me in Cape Colony, viz., those in the Malmesbury beds of Van Rhyn's Dorp, the Piquetberg and Worcester districts, and the Cango limestones.

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The Glacial Beds.

The conglomeratic rocks which occur at or near the top of the Griqua Town series are particularly interesting, because they contain distinctly striated and flattened pebbles and boulders, which certainly owe their characteristic shape and scratches to glacial action.

The matrix is yellow, brown or red in colour, according to the state of the iron oxide present, but in a few cases a white or pale grey rock is met with three or four inches below the surface. The outcrops are generally very dark brown or red, almost black, in consequence of the concentration of iron oxide. The white rock seems to be due to the leaching out of the colouring matter; the subsequent veins in its neighbourhood are of white quartz, and the white patches of matrix appear to be irregular in shape, but more or less confined to parts equi-distant from visible joints and the outer surface. In the glacial beds on Juanana there is less iron oxide than elsewhere, and a thin section (1,457) shows a fair amount of carbonates, probably calcium carbonate, with little or no magnesium carbonate, distributed through the rock in patches. These patches are in many cases sections through rhombohedral or scalenohedral crystals; in others, the boundaries are quite irregular. In ordinary light they are scarcely distinguishable from the rest of the matrix, for they enclose the dusty matter and grains of quartz, etc., just as the usual matrix of the rock does. The patches of calcite rarely reach a millimetre in length. The usual matrix is apparently siliceous; it looks like a chert with very fine texture; but it encloses so many small particles of indeterminate substances, as well as very small grains of quartz and other minerals, that its cherty nature is masked to a great extent. In several places, however, the rock, as a whole, breaks with a cherty fracture. The chief constituent, in the form of small angular grains, is quartz, but chert fragments are fairly abundant, as would be expected from the amount of that substance in the rock in the form of pebbles. Felspar is represented by a few grains of repeatedly twinned acid plagioclase, such as is found in many granitic rocks; microcline is absent from this section, and from the section of the grits associated with the glacial beds on Juanana (1,456). There are no other determinable fragments, though one brown fragment may be tourmaline. There is much greenish chloritic mineral scattered through the matrix; but it is probably not an original constituent of the rock.

No sections through the red and brown rocks have been made, but, so far as can be judged from hand specimens, these differ from the Juanana rock merely in the greater abundance of iron oxides.

The boulders reach a length of about a foot, and the great majority of them are cherty rocks; a few grits and fine-grained

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quartzites have been noticed, but not a single specimen of granite, gneiss, diabase, or other igneous rock has been found. Limestone pebbles have not been seen in the rock, but there are occasional cavities with smooth surfaces which may represent limestone pebbles now removed by solution. These cavities are often partly filled by hydrated iron oxides. In the red rocks, specular iron is very often seen in such holes, and also in the general matrix.

The hardness of the matrix makes it difficult to break the boulders from the rock; generally the fracture passes more readily through the boulder than round it. Several specimens were, however, broken out, with parts of their surfaces exposed to view, and some of these are covered with striations. The best examples of striated stones, however, were found on the surface, they having been loosened from the matrix by the effects of changes of temperature and the action of air and water. In some cases well striated blocks were found with the original matrix still covering parts of the striated surfaces in such a way as to prove that the scratches were on the rocks before they were removed from the matrix.

The scratches are excellently preserved on the cherts; the surface of a flattened oval pebble may show several sets of scratches, or a few deep scorings crossing a set of finer scratches. In such cases the pebble has not been greatly changed in form during the production of the scratches; in many cases a part of the boulder has evidently been removed by the same process which made the scratches, and it is now left with one or more flattened surfaces covered with scratches. The striated pebbles and boulders, so far as their shape is concerned, may be matched by many striated stones from the Dwyka series, or from the more recent tills of other countries, and there is no reason to doubt the glacial origin of the striated stones from the Griqua Town beds of Hay.

The glaciated boulders were obtained at many places both on the west and east sides of the great syncline of volcanic rocks which occupies a large area in the middle of the district. The localities will be mentioned later.

In places the pebbles are sufficiently abundant to give the rock the character of a conglomerate, but more usually they are scattered at various intervals through the fine-grained matrix.

The origin of the boulders is a question which cannot now be considered with advantage, because the rocks which make the boulders yet studied are only cherts and fine grits, and so far as our present knowledge of the country goes, they do not lend themselves to a solution of the problem.

Amongst the boulders in the glacial rocks there are often to be seen flattened oval lumps of chert, with a distinct nodular appearance, sometimes with a keel-like edge all round them and other signs, such as an indistinct banding, of having been

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isolated masses in clayey or calcareous rocks. The shape of these lumps of chert is not that of water-worn pebbles, though there are numbers of obviously water-worn chert pebbles in the same beds, but they are more like the oval limestone concretions in some marls and shales. I obtained several of these oval cherts with well striated surfaces.

Distribution of the Griqua Town Series.

(1.) *The Asbestos Mountains.*

From the banks of the Orange River above Kliphuis the magnetic jaspers of this series stretch in a north-north-easterly direction past Griqua Town and the Peiser mine into the Barkly Division. This belt is the Asbestos Mountains of the maps, but although the ground rises rather sharply from the country on either side, the hills do not reach a greater height than about 700 feet above it. Only a small part of this area has been traversed as yet; the south end is cut up by more or less longitudinal valleys, partly filled in with the Dwyka formation, and the modern valleys cut across these old lines of drainage. The top of the range is fairly flat, although the rocks do not lie horizontally, but are at places sharply bent.

A section through Krantz Fontein and neighbouring farms is shown in Fig. 1. The Griqua Town beds at this end of the range are chiefly thin banded magnetic jaspers; the jasper is most frequently yellow or brown, and different layers show slightly different tints. Dull red layers are often seen, but the red rock is less abundant than the brown and yellow. Occasionally the rocks are fine-grained sandstone, rich in limonite and magnetite, more rarely containing haematite. These softer beds give rise to caves on the sides of the kloofs.

On large surfaces of the jasper, undulations, which look very like ripple marks, are to be seen at places. It is sometimes the case that these ripples affect only a single layer of rock, and the succeeding bed fills up the hollows and itself presents a plane surface; in such cases the markings are original, and were doubtless caused by currents in the water under which the sediments were laid down. In other cases, however, the markings are of subsequent origin. At the head of the kloof leading southwards to the homestead on Krantz Fontein, there is a band of corrugated rock, of which the surface at any horizon within the band looks as if it were covered with ripple marks. I traced this rock, which lies nearly horizontally, for over 100 yards from east to west. It is two feet thick where best exposed, and the overlying and underlying rocks are precisely similar, but without corrugations. The rocks consist of thinly banded magnetic and brown jaspers, with numerous layers of yellow fibrous quartz (altered crocidolite), which are continuous for at least

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several yards in the flat-bedded part of the rock. The corrugations extend with the same axes, *i.e.*, along the same lines, right through the two feet of corrugated rock; the length of the waves is about nine inches, and their amplitude one and a half at most, but this amplitude decreases gradually above and below, bringing about the passage into the flat-bedded rock. The altered crocidolite is thicker in the crests of the waves than elsewhere, and sometimes does not reach the troughs at all. The trend of the undulations is about the same as that of the greater folds on the same farm, *i.e.*, N. 20° E.

Along certain lines the jaspers on Krantz Fontein are brecciated. One band was followed for 400 yards; it is made of pieces of the jasper, set in a siliceous and haematitic matrix; the broken rock is 20 feet wide at the most; it gives rise to large rounded outcrops, not unlike those of dolerite dykes in a dry climate.

Certain beds on Krantz Fontein and Wilgebooms Dam are very full of magnetite, and are black in colour. It is an interesting fact that in this rock the crocidolite and the yellow mineral resulting from its alteration are represented by white fibrous quartz.

A good section through the Asbestos Mountains is afforded by the valley which runs diagonally across the range from Claradale to the Orange River. This valley was only examined as far as Kafir Krantz. The beds are not so disturbed as are the same rocks on Krantz Fontein. The steep hillsides south of the valley on the Kloof are noted for the variety of the alteration products of crocidolite which have been obtained there.

FIG. 1.—Section through Krantz Fontein to show the relation of the limestones to the Griqua Town beds, and of the Dwyka outliers to the older rocks. Horizontal distance, 12 miles: horizontal to vertical scale, 1:10.

From Punt northwards to the Barkly West Division the Griqua Town beds dip west-north-west under the volcanic series of Ongeluk, but only that part of the line of junction north of Manby (O. 7) and south of Peiser's mine has yet been examined.

An account of the section across the range from Griqua Town to Taaibosch Fontein will probably illustrate its structure for a considerable distance both to the south and north of Griqua Town.

The lowest beds seen near Griqua Town are yellow jaspers, with thin layers of magnetite. The junction with the underlying limestones of the Campbell Rand series is not seen here, and the lowest of the banded jaspers are considerably contorted and broken, though the beds seen on the lower slopes of the hills are not disturbed in a similar way. I have not seen a good clear section near Griqua Town, in which the nature of this local disturbance can be ascertained, but such a section is certainly exposed at " Ramaje's Kop," near Daniel's Kuil, described by Stow,[1] which has not yet been visited by the Geological Survey. Stow says the jasper rocks lie in " small trough-like hollows " in the undisturbed limestones of the Campbell Rand group, and that the jasper rocks are greatly contorted. He attributes the disturbance to pressure acting from the west, but does not account for the undisturbed condition of the limestone. The local disturbance of the base of the Griqua Town beds was seen again near Groen Water, and has taken place on a gigantic scale in the Blink Klip Field Cornetcy, in connection with which the matter will again be considered. At Enkelde Wilgeboom the succession from the limestones upwards is quite normal. At all these places the limestones themselves are not disturbed; they lie flat or dip at moderate angles under the jasper rocks. Neither at Griqua Town or elsewhere are there signs of thrust at this horizon, unless the dislocation of the jaspers be considered evidence to that effect. The explanation of these local disturbances is probably to be found in the collapse of the lowest jaspers into cavities formed on the surface of the Campbell Rand group by solution.

The banded jaspers have a regular dip towards the west-north-west, but the angle varies up to 35°; it is more usually from 5° to 10°, sometimes, especially towards the west side of the range, less than 5°. Softer beds, ferruginous sandstones, and shales are occasionally met with where small exposures have been made along the road-side; red jaspers are rarely seen in this neighbourhood. A well-marked escarpment, with a krantz of varying height, rises on the right side of the valley on the eastern part of Taaibosch Fontein; this escarpment is formed by the glacial beds, and excellent sections through them are readily found. These beds make three prominent hills a few miles to the north of the Taaibosch road. The kopjes, one of which is the Orpen's Kop mentioned by Stow,[2] are near

[1] Q. J. G. S. XXX., p. 665, and Pl. XXXIX., fig. 8.
[2] *Loc. cit.* p. 627.

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the road from Griqua Town to Moss Fontein, and one of the boundary beacons of Griqua Town Commonage is on one of them. The glacial beds are brown, and they vary in texture from place to place according to the amounts of iron ores and silica in them. They are very tough rocks or splintery, and the contained pebbles and boulders are not easily got out. The weather has loosened many of the boulders, and beautifully striated stones are to be obtained amongst the outcrops. In places the inclusions are sufficiently numerous to make the rock a conglomerate, but usually the boulders and pebbles are scattered at considerable intervals through the matrix, in a way that recalls the distribution of the boulders in the southern Dwyka and in the glacial rock in the Table Mountain series near Clanwilliam. The boulders are made of cherty rocks and fine-grained grits. These beds are well displayed on the dip-slope down which the road to the house on Taaibosch Fontein is carried. There is an alluvial flat separating the glacial beds from the igneous rocks of the main valley on Taaibosch Fontein, but they certainly dip towards the latter. On the west side of this valley there is a fault, along which the beds are dropped on the eastern side, so that the upper part of the Griqua Town beds and the lowest portion of the Ongeluk beds are repeated. It is possible, however, that the igneous rocks of the Taaibosch Fontein valley are intrusive, and do not belong to the Ongeluk lavas.

The thickness of the Griqua Town series, as calculated from the width of outcrop and average dip of the beds a few miles north of the village, is 2,500 feet. Along this line the beds are probably less disturbed than further south, and unless there are strike faults with downthrow to the east, the above estimate is near the truth.

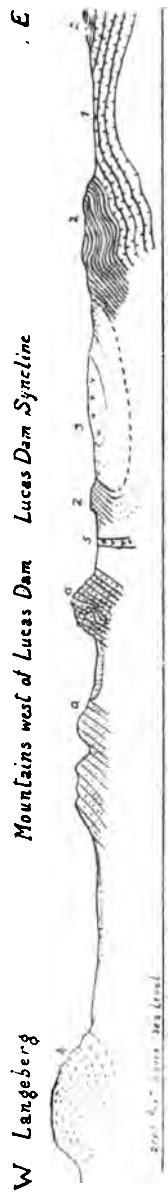

FIG. 2.—Section through the Langeberg area in the N.W. corner of Hay. 1. Campbell Rand series. 2. Griqua Town series. 3. Ongeluk series. 4. Matsap beds. 5. Dyke of dolerite or diabase. *a*. Quartzites, slates and conglomerates of uncertain age. Distance, 17 miles; horizontal to vertical scale, 1:2.

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(2.) *The Koegas and Paarde Kloof Field Cornetcies.*

The Griqua Town beds in the east of Koegas Field Cornetcy are continuous with those in the south end of the Asbestos Mountains. The most interesting area is that between Niekerk's Hope and the Juanana syncline of volcanic rocks. The Griqua Town beds are here much less silicious, and have less iron oxide in the form of magnetite and haematite than in the Asbestos Mountains. They lie at low angles, and give rise to many Kopjes, which recall by their shape the dolerite or sandstone capped hills of the Karroo.

The hill on which the N.W. beacon of Rooi Laagte (O. 351) stands is a typical example of these Kopjes.

The following is a roughly measured section taken on the eastern side of this hill:—

Brown calcareous sandstones, with much iron, partly in the form of carbonate; weathers with joints marked by concentration of iron oxide	20	feet.
Shales with thin beds of crystalline limestone and sandstone...	100	„
Hard blue clayey sandstone, making a strong rib on the hillside	2	„
Shales and thin sandstones	90	„
Hard blue sandstones, slightly calcareous ...	30	„
Shales and their sandstones	70	„
Hard grey sandstones	4	„
Shales and sandstones...	80	„
	396	feet.

The shales which form so large a part of the hill are dark rocks, rather hard but thinly laminated, and some beds at least contain carbonates. At this locality the rocks dip at about 3° W.N.W., but a shallow syncline brings in the same beds on the crests of some hills between Rooi Laagte and Juanana; just east of Juanana they dip down at angles of from 3°—5° under the volcanic rocks, and the glacial beds intervene between the two.

The country south-west of Juanana, as far as Hakschin, has not yet been mapped.

Immediately west of the Juanana volcanic rocks the uppermost beds of the Griqua Town series seen are thin limestones, including a breccia with limestone matrix, brown, blue, and green heavy ferruginous sandy rocks often finely banded. There is a strip of ground covered with sand between the volcanic beds and these western sedimentary rocks and the glacial beds have not been seen there. There are considerable differences between the Rooi Laagte beds and these, but the change is evidently an intermediate stage, leading to the magnetic and siliceous rocks so characteristic of the Griqua Town series.

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On Randjes, Waterkloof, Stinkwater, and Tolo, the Griqua Town beds again dip down under a syncline of volcanic rocks. This area, as far westwards as Piljaar's Poort, was visited before the evidences of glacial action in the top beds of the series had been discovered, and so the glacial beds were not looked for. Whether they exist there is at present uncertain.

On Tolo there is a fine section through some 700 feet of the upper part of the series; heavy blue and green rocks mostly, with some thinly laminated beds; thin limestones and dull red haematitic rocks occur, as well as fresh cherts containing small crystals of magnetite. The hills on which this section is found rise some 500 feet above the direct road from Abram's Dam to Griqua Town, and they lie on the northern side of it. From the top one has an excellent view of the broad anticline of Griqua Town beds, with its axis running about S. 10° W., which carries the beds under the volcanic rocks of Juanana on the east and of Abram's Dam, etc., on the west. Towards the north there lies a rather rugged tract of country, evidently formed by Griqua Town beds lying at low angles.

West of the Abram's Dam syncline heavy ferruginous rocks, accompanied by thin blue dolomites, rise from under it, and below them there are red and brown magnetic jaspery rocks. This succession is repeated on account of the westward dip of the beds before the Paarde Vley syncline of volcanic rocks is reached.,

West of the north end of this syncline the Griqua Town beds are bent into another anticline, which brings them down under the volcanic beds on Leelyk's Dam.

South of the Leelyk's Dam syncline there is a wide area of the Griqua Town beds on the farms Grasgat, Kwakwas, Pypwater, Hounslow, Koegas, and Leelyk's Staat. In this area the beds again assume the same characters as they have in the Asbestos Mountains and the Doornbergen, but flanking the west side of the Paarde Vley syncline there are thin limestones, interbedded with cherts and haematitic rocks near the top of the series. On Koegas, Hounslow, Leelyk's Staat, and Pypwater the bulk of the rock is brown and yellow magnetic jasper, with layers of the heavy blue rock containing much crocidolite distributed through it. Crocidolite, in the form of asbestos, as well as the oxidised and silicified varieties, occurs on these farms, and is worked by the Cape Asbestos Company, to whose manager, Mr. T. Olds, I am indebted for much information.

In this part of the district the Griqua Town beds become considerably disturbed, and near the Orange River the prevailing strike is nearly north-west, instead of north-north-east, as in the Asbestos Mountains and the rest of Hay. This change of strike shows that the rocks are here folded parallel to the Doornberg folds, and the Orange River has made a passage for itself along the Campbell Rand beds below the sharp bend on O. 322.

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On Leelyk's Staat, Stilverlaats, and the two farms called Witberg (O. 315 and O. 316), the colouring matter in the jaspers is very often haematite.

A few inliers of magnetic haematite schistose rocks occur on Piljaar's Poort, rising out of the sand between the bifurcated southern end of the Langeberg ridge. These schistose rocks are probably sheared Griqua Town beds; with them are associated some pink and white cherts, with dark magnetic and haematitic layers. The isolated outcrops in this sandy country cannot be directly connected with any large mass of Griqua Town beds, but their strike is parallel with that of the Griqua Town series on Stilverlaats and O. 315 (Witberg).

In the neighbourhood of Matsap, on both sides of the outlying range of Matsap beds, the Griqua Town beds are well developed, though their base is not seen. Between the Matsap ridge and the Langeberg they form a wide tract of hilly country, which includes the "ridges near Potgieter's" of Stow's paper,[1] and on the east of the Matsap ridge lie the Rooy Kopjes[2] of the same author. Both these formations were separated from the Griqua Town group by Stow, but there is no good ground for doing so.

In lithological characters the brown, yellow, and reddish banded and magnetic jaspers of the hills between the Matsap ridge and the Langebergen can be matched in the Asbestos range and the Doornberg; the heavy blue rocks containing crocidolite are exposed on Witdraai and O. 203. Both the asbestiform crocidolite and its alteration products are found in the same hills. Though neither the top or bottom of the series has been seen in that neighbourhood, I saw from the hill tops an area to the south-south-west where these strata appear to dip under the north end of the Ongeluk volcanic series of the Abram's Dam syncline. Lack of water in that area prevented the work from being completed last season.

These hills are a broad anticline, rather irregular in structure, stretching north-north-east. The rocks then dip under the Matsap ridge, though faults probably complicate the conditions there.[3]

On the east side of the Matsap ridge the red magnetic jaspers reappear. They are especially well-exposed round the south end of the ridge, where the Matsap beds lie upon them. It is in this neighbourhood that the glacial conglomerate near the

[1] *Loc. cit.* p. 663, also pp. 633-637. "Potgieter's" is the farm now called Plaatjes Dam or Oudmeides Kloof.

[2] *Loc. cit.* p. 663, also pp. 629-632.

[3] Stow considered that the red jaspers were older than the Matsap beds, and that the yellow and brown jaspers were younger than the same formation. He took this view because red jasper pebbles are found in the Matsap beds, and his experience led him to think the brown jaspers on either side of the Matsap ridge lay above the Matsap quartzites, *loc. cit.* pp. 630 and 635; also Cape Monthly Magazine for Aug. 1872, p. 69.

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top of the series is very well exposed; it occurs in a syncline between the Ongeluk volcanic rocks (seen on Van Nels Dam, Prairie, and Dell, etc.), and the Matsap ridge on the farms Lang Kloof, Water Kloof, and Koodoo's Kloof. It is overlain by some highly haematitic rocks and cherts; the junction with the volcanic rocks to the east is hidden, but the dip is towards the latter on Range and Eden. The matrix of the glacial boulder beds is here a hard haematitic rock, and specular iron (a flaky form of haematite) occurs in holes in the rock. The glacial beds are about 100 feet thick in this area.

The beds associated with the glacial rocks here contain a very large amount of haematite, a mineral that is especially abundant in the Griqua Town beds in the west of Hay.

The brown and yellow banded magnetic jaspers form some prominent flat-topped hills on Kaffir Kop, Abel's Vlakte, Kopje and Vaal Water. They contain layers of silicified and oxidised crocidolite. As a whole, these beds lie at low angles, but there are sharp contortions in them. East of these hills there is much sand, through which the smaller hills that Stow called the Rooy Kopjes project. These are made of deep red jaspers, with black magnetic layers, and some whitish cherty rocks are interbedded with them. They are on the farms O. 72 (Kain's Vlakte), O.78, and O.86. The beds dip at about 5° towards S. 10°—20° E., *i.e.*, towards the Ongeluk volcanic series, but several hundred yards of sandy ground lie between them, covering up the glacial beds if these are present at their usual horizon.

(3.) *The Blink Klip Field Cornetcy and the Groen Water Area.*

In this part of the Division the Griqua Town beds occur as a wide anticline, which brings the Campbell Rand limestone to the surface in the greater part of the area. Near Groen Water the Griqua Town beds, consisting of yellow and brown magnetic rocks and the heavy blue rocks which contain crocidolite, dip south-eastwards away from the limestones and towards the Ongeluk series. The glacial conglomerate is exposed on the west side of M. 19, just west of the lowest volcanic outcrops.

On the west of the area the Griqua Town beds have a less simple boundary; in the north they dip under the Vlak Fontein volcanic syncline, reappear again only to dip under the overturned syncline (see fig. 3) on Lucas Dam. They are last seen in the remarkable ridge of yellowish, brown, and red jaspers and magnetite rocks, with interbedded limestones and white quartzites, which stretches from the Vryburg border to Floradale (O. 230), a distance of 16 miles in a straight line. This ridge is sharply defined and runs straight, and two southern inliers projecting through the gravel and sand on O. 229 show that it continues still further than Floradale. In this neighbourhood the sandy soil is thick, and conceals the rocks over many

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areas where the structure is doubtful, but on the east side of the ridge at Lucas Dam a chert boulder rock exists between the ridge and the volcanic rocks; the bed itself is not exposed, but typically striated stones were found along the strip of country where the rock should be. Their occurrence is of importance because the rocks in the ridge dip at a high angle towards W. 10° N., away from the volcanic beds on Lucas Dam, which very probably belong to the Ongeluk series. The western side of the syncline is thus inverted. The nature of the junction with the shales, quartzites, and conglomerates of the high ridge on the western boundary of the farm is doubtful. The Griqua Town beds dip under the latter, but the shales, conglomerates, and quartzites are not like any rock in the Griqua Town or

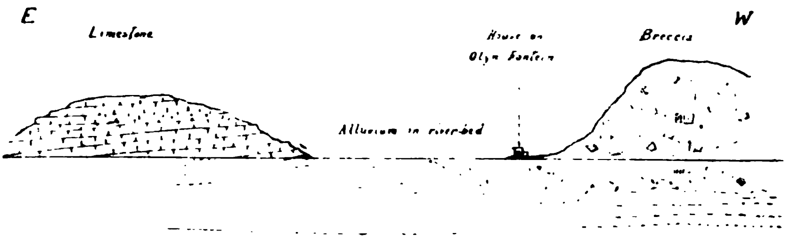

FIG. 3.—Section through the breccia hill on right bank of Postmasburg River to show its probable relation to the limestone on left bank. Vertical and horizontal scales the same.

Campbell Rand Series. They are near the Matsap beds of the Langberg, and will be discussed in the section of this Report which deals with the Matsap beds, though it is still doubtful whether they belong to that group.

The southern end of the broad limestone anticline must lie between Leeuw Fontein and Bonnet Fontein, but owing to gravels and tufaceous limestones, the outcrops are concealed to a great extent, and the single traverse I made through that area was not sufficient to determine the position of the boundary between the Campbell Rand and the Griqua Town series.

The top of the Griqua Town group is again seen on Sunnyside, M. 77. The glacial beds are well exposed there, and dip towards a small area of the Ongeluk volcanic series on the same farm. There is an interesting occurrence of pieces of chert with flat sides meeting at various angles in this outcrop of the glacial beds. These inclusions are embedded with the striated rocks in a hard brownish siliceous matrix, but they have only a few scratches on them, and the scratches are neither so long or so deep as those on the typical striated stones. In some cases the greater part of the surface of the fragment is formed by the flat faces, and in others only two or three flat

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faces are shown, the rest of the surface being irregular. The edges along which the flat faces meet are remarkably straight, a consequence of the flatness of the faces, which seems to me to be a very extraordinary feature. These stones look as if they came from a rock in which jointing was unusually well developed, but in a somewhat irregular manner, as two faces never appear to be parallel to one axis. Striated stones are quite as abundant in this locality as in any other visited.

The ridge which ends on Sunnyside is an anticline at the south end, but north of that farm the west limb alone remains, the east limb turns eastwards with south-easterly dip—but the connection with the Griqua Town beds on the east or left side of the Postmasburg river has not been made out.

Along the road from M. 93 to Lucas Dam a fairly continuous section through the Griqua Town beds, with the exception of the uppermost portion, can be made out, though the thicknesses assigned to the various groups of beds are not accurate, as no allowance could well be made for small faults and differences in dip, which are doubtless present. The section is as follows, in downward succession:—

	Feet.
Massive and thin bedded brown and yellowish jaspers, with layers very rich in magnetite...	700
Purple quartzites	50
Red and black ferruginous bedded rocks, softer than the jaspers	500
Greenish soapy quartz grit, like the steatitic rocks at Klip Fontein, 6 inches.	
Greenish quartzites, with occasional micaceous layers	300
Dark ferruginous rocks, with occasional layers of massive haematite	560
White quartzites	150
Ferruginous thin bedded rocks, red and black in colour...	780
Limestones (Campbell Rand group).	
	3,040 feet.

Parts of the section are concealed under sandy soil, and a stretch of sand quite a mile wide separates the westernmost outcrops of brown jaspers from the nearest volcanic rocks to the west. Though crocidolite and its altered forms were not seen on the line of section, they occur further south on the same hills.

The glacial beds crop out in a stream bed leading westwards from the Poort on Paling, and they are underlain by heavy blue-black rocks. They dip westwards at a rather high angle. The glacial boulder bed is softer here than elsewhere. The boulders are made of chert. This small area must be

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separated from the Matsap beds to the east by a fault, with downthrow to the east, and from the small patch of Campbell Rand limestone shown in fig. 5 by a second fault. The outcrops are too few to allow the structure to be ascertained definitely.

The Blink Klip Breccia.

This rock was described and given the above name by G. W. Stow.[1] Blink Klip is the old Dutch name (probably given by the Griquas) for a locality[2] near the village now called Postmasburg, from which the natives obtained red pigment. The red powder is specular iron in very small scales, and these give a glittering appearance to the rocks in the neighbourhood.

The rock is a breccia[3] of peculiar character; the fragments are sharp edged and of all sizes up to many yards, or even scores of yards in length, and the cement is siliceous or haematitic. The fragments consist of banded magnetic jaspers, usually coloured red with haematite, and cherts, just like the rocks which make up so large a part of the Griqua Town series; the blue heavy rocks which contain crocidolite have not been recorded from the breccia, nor have the altered forms of crocidolite. In many cases a rock consisting almost entirely of haematite shows on fresh surfaces the outlines and banding of fragments now converted into haematite. These outlines are barely visible, but on some weathered surfaces the original form of the fragments is more easily seen, owing to different rates of weathering along the variously arranged haematite crystals, and probably also owing to the presence of more silica in the fragments than in the matrix, or *vice versa*.

The specific gravity of a piece of the matrix, apparently free from large inclusions, is 5·17. No analyses have yet been made of these rocks, but they evidently contain much more iron than the usual ferruginous beds in the Griqua Town series, of which the specific gravity is about 3·4.

The chief mass of the Blink Klip breccias is that which forms the range of hills running north-north-east from Olyn Fontein, near Postmasburg, into the Vryburg Division; part of this range is called the Klip Fontein hills. Outlying masses occur on both sides of the main ridge, and on Paling there is another ridge, which must be continued into Vryburg. On Doorn Fontein there are at least two outliers, and a large mass occurs on Wolhaar's Kop.

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[1] Q. J. G. S., Vol. XXX., pp. 651-653.

[2] Called Sensavan formerly by the natives. See Burchell, I, p. 414 and II, pp. 255, and 258, 318.

[3] In "Die Kalahari" p. 633, Dr. Passarge suggests that the Blink Klip breccia is a surface debris formed and cemented together when the surface features were different from what they now are. This, however, is a quite impossible explanation, as the account of the breccia at Klip Fontein and at Wolhaars Kop will show.

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On the right side of the river at the south end of Postmasburg there is a hill made by breccias rising 150 feet above the river bed. The whole hill, which is about two miles long and a mile wide, seems to be made of fragments of red haematite and black magnetic jasper, with occasional layers of white and pink chert, cemented together by haematite and silica. In places there seems to be more matrix than fragments, in other places the fragments are merely huge blocks of banded rock shattered into innumerable pieces, hardly displaced from their original relative positions; the matrix fills the interstices, which may be mere cracks or may be a quarter of an inch wide. These great shattered blocks may have their laminae lying horizontal or nearly so, in conformity with the bed-planes of the neighbouring Campbell Rand limestone, or they may be in any other position. On the left bank of the river the Campbell Rand limestones crop out down to the river bed, and they have a slight dip to the east, so that the breccia is certainly at a lower level on the right bank than the limestone on the left; the river bed, about 100 yards wide, intervenes between the outcrops. The accompanying figure (fig. 4) shows the relationship of the two rocks so far as it is visible. Unfortunately the thick covering of sand on the west side of the hill prevents the section from being completed on that side, but flat outcrops of limestone occur between this hill and the south end of the greater ridge to the west. On the left bank the limestone is traversed by rather wide joints filled in with haematitic breccia, which can be followed for many yards across the veld. The breccia in these widened joints is like the less coarse parts of the breccia in the hill. The dotted lines in the figure below the level of the river bed will explain the way in which the breccia probably rests on the limestone. The hollow in the limestone occupied by the breccia certainly exists below the east side of the hill, but there is no evidence of its existence under the west side, for the sand conceals the outcrops there. It is possible, but not likely, that there is a fault with downthrow to the west on the eastern flank of the hill.

Two small outliers of the breccia near Postmasburg on the left bank of the river were noticed, and there must be many others not big enough to be seen from a distance.

The two outliers about three miles above the village on the right bank of the river are conspicuous hills, and they have very rugged outlines. At the base of the smaller hill, the one from which natives have obtained red paint from time immemorial, the limestone crops out within a few feet of the breccia, though a vertical section showing their relation is wanting. The limestone lies horizontally; on the east side of the valley, about 200 yards from the outcrop on the right bank, the limestone dips at a very low angle towards E. 10° S.

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FIG. 4.—Section through the Asbestos Mountains near Griqua Town. Distance, 17 miles. Horizontal to vertical scale, 1:5. 1. Campbell Rand series. 2 and 3, Griqua Town series (3 is the glacial conglomerate). 4. Ongeluk volcanic series.

The breccia on these hills is very similar to that described above from near Postmasburg. Its position relatively to the limestone is not quite so clearly seen, but the limestones of the left side of the valley would abut against the breccia if they were carried across the valley with the same dip.

The Klip Fontein hills are part of the western ridge of breccia which starts on Olyn Fontein; the outlines of the range are rough throughout, and parts stand out prominently, while close at hand there may be two or more deep cuts through the hills without any apparent connection with stream action. At Klip Fontein the hills are between 400 and 500 feet high. The kloof which opens out near the homestead affords a section along the axis of the range, and cliff sections on the outer sides, both east and west, are numerous.

The structure of these hills is very complicated, and to make a detailed map of two or three square miles would have taken more than a week. The whole mass, with the exception of a band of flaggy steatitic slates near the bottom of the kloof, is made of breccias like those described from Postmasburg, but cherts are rather more prominent at Klip Fontein, and there are many outcrops of black and white quartz rocks, which appear to be vein quartz filling irregular spaces and coloured with iron oxides. This quartz has a different appearance from the usual siliceous matrix; it is less chalcedonic and more like ordinary vein quartz.

The individual fragments in the breccia increase in size, on the average, from the bottom of the hills upwards, and on the top one finds huge blocks, brecciated to a certain extent, and displaced from the horizontal, but arranged in a more or less orderly fashion. Between the blocks there is breccia of smaller-sized pieces. The

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blocks may reach a length of 100 yards or even more. On the nearly flat top of the Klip Fontein ridge on each side of the central kloof the great dislocated blocks dip at various angles towards an axis which coincides with the direction of the kloof, and at the top end of the kloof the blocks dip down towards it, while at the south end the peculiar steatitic slates dip up the kloof. The whole arrangement of the blocks gives one the impression that horizontal rocks were fractured and sank into an elongated hole, the interstices being subsequently filled up with haematite and silica.

The large blocks of banded rocks seen near the top of the hills are occasionally found to have their laminae contorted, but this is by no means usually the case. Generally, the rocks appear to have been broken without having been bent.

There is some steatitic mineral in layers closely associated with the jaspers in the Klip Fontein hills. There are also small irregularly shaped strings of a soapy substance in parts of the brecciated rocks. The steatitic slates mentioned previously are rather peculiar rocks; they have not been shattered to the same extent as the jaspers and cherts, but their general arrangement agrees with that of the larger blocks of the latter. The steatitic rocks have not yet been examined microscopically, for the sections are not at present available.

In connection with the Klip Fontein hills there is an interesting outcrop of a quartzitic rock, with small pebbles of chert, on the east side of the hills about three miles north of the homestead. The rock crops out close to the base of the hills, and dips towards them. It is interesting, because similar conglomerates have been described from the base of the Pretoria beds in the Marico district.[1]

The hills near the gap through which the road to Lucas Dam from Postmasburg passes are part of the same range as the Klip Fontein hills, and they are made of similar rocks. A small outcrop of limestone was met with in the middle of the gap. Some of the low lying breccia outcrops contain huge masses of contorted and broken banded rocks, now converted into haematite.

On Paling the Blink Klip breccias form a ridge which is continued into the Vryburg Division. Dolomitic limestone occurs on the flat ground between this ridge and the Klip Fontein hills; on its western side the breccia is overlain by the Matsap beds, which dip a few degrees north of west.

On Wolhaar's Kop the breccia appears in the axis of an anticline. On the west side the breccia passes into unbroken Griqua Town beds, which dip under the volcanic rocks of Floradale (O. 230), but the eastern limb has been denuded away near Wolhaar's Kop, though it is preserved on Sunnyside three and a half miles to the south, where the lower beds have been carried below the surface. The thickness of the breccia on Wolhaar's Kop must be more than 200 feet thick.

[1] Hatch, F. H., Trans. Geol. Soc. S. A., Vol. VII,, p. 1. Holmes, C. G., Trans. Geol. Soc. S.A., Vol. VIII., p. 167.

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There are low hills of the breccia on the Vryburg boundary line between Klip Fontein and Riet Fontein (Barkly West). Mount Huxley seems to be the name of a hill just across the Vryburg border, and not on it, as is stated on the 12·6 miles to the inch map of the Colony. In Stow's[1] section, Fig. 7., Pl. xxxix., the name is given to a hill between Blink Klip and Klip Fontein, though in his map, Pl. xxxiv., it is placed north-east of Klip Fontein.

Origin of the Breccia.

Stow[2] considered the breccia to be a detrital rock derived from the breaking up of the Griqua Town beds. This explanation is not acceptable. The character of the rock is quite different from that of a detrital breccia. The huge angular blocks, often shattered, but without dispersal of the fragments, lying amongst smaller angular fragments, are without parallel in an ordinary breccia. The arrangement of these great blocks on the top of the Klip Fontein hills is another obstacle, and so is the apparent absence of pieces of foreign rocks, such as granites and diabases. Then, again, on Wolhaar's Kop, the breccia is overlain by normal Griqua Town beds, into which it passes gradually, which negatives the supposition that the fragments in the breccia came from the Griqua Town beds by the ordinary processes of atmospheric denudation. The exclusively angular shape of the fragments is another difficulty.

It is clear that some other explanation must be found.

One obviously important fact is that in every locality where the breccia occurs it very probably lies upon the Campbell Rand limestones, *i.e.*, it replaces the lower part of the Griqua Town series by a mass of fragments of these same beds, re-cemented by iron ore and silica. This recalls the fact that the base of the Griqua Town beds near the village of Griqua Town are sharply contorted, and also the descriptions by Stow[3] of the hollows in the surface of the limestone at Ramaje's Kop, in which the lowest beds of the Griqua Town series are lying. Stow attributed the appearances at Ramaje's Kop to the unconformable position of the Griqua Town beds on the limestone and thrusting from the west during and after the deposition of the Griqua Town beds. No other evidence has been obtained for the existence of the unconformity, and there are obvious difficulties in the last part of the explanation.

If we suppose the limestone to have been dissolved away in certain areas after the Griqua Town beds had been laid down, probably after they had been converted into magnetic jaspers, much difficulty is removed. The brittle jaspery rocks sank irregularly into the cavities thus made, perhaps during a period of

[1] Q. J. G. S., Vol. XXX.
[2] Q. J. G. S., XXX, p. 653.
[3] Q. J. G. S., XXX., p. 665.

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earth movements which started the collapse. Where great cavities existed great thicknesses of breccia were formed, but the brecciation became less upwards, so that unbroken Griqua Town beds lay upon the breccia. Where solution took place on a small scale only, we find crumpled strata at the bottom of the Griqua Town series, as near the village, overlain by beds not so disturbed.

The haematite and silica must have been introduced after the main part of the brecciation process had taken place .

The fact that the breccia crops out below the level of the limestones below Postmasburg is important, as showing that this mass of breccia may lie in a hollow dissolved in the limestone, but proof of such a position in the case of this and the other breccias has not yet been obtained. The filling up by breccia of irregularly widened joints in the limstone would be expected under the conditions supposed to have obtained during the formation of the breccia.

The greatest development of the breccia is along anticlinal axes, yet the unbroken rocks on the Wolhaar's Kop anticline do not dip towards the breccia. If the folding to which the anticlines are due also started the disruptive action this state of things can be understood. The slight divergence of dip between the limestones and the unbroken Griqua Town beds which would be expected on this hypothesis has not been noted, but its observation would in any case be a matter of difficulty. That the breccia is due to earth-movements in the ordinary sense is very improbable, for no sign of thrusting is observable in the localities where the breccia occurs, and this rock does not resemble any breccia known to me which is supposed to be due to that process.

A case of the collapse of Karroo beds into hollows dissolved out of dolomite near Pretoria is described by Molengraaff,[1] but but I have not met with a description of phenomena due to this process on such a large scale as is implied by the Blink Klip breccia of Hay.

The Ongeluk Volcanic Series.

This group occupies a large part of Hay. Stow called them " Amygdaloidal and associated rocks of Pniel, Vetberg, etc.," on the map, pl. xxxv.[2] and " amygdaloidal rocks of Ongeluk and Moss Fontein," on p. 662 and elsewhere. He identified the Hay volcanic rocks with those of Pniel and the Vaal River valley (belonging to the Ventersdorp system of Hatch and the Vaal River system of Molengraaff), on account of their resemblance, but his sections show what difficulties this led to. Dunn placed both the Hay volcanic rocks and those along the Vaal River in

[1] Geology of the Transvaal, 1904, p. 78.
[2] Q. J. G. S., Vol. XXX.

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one group of "Diabase later than the Lydenburg beds," but he does not explain how the Vaal River rocks can be got into that stratigraphical position, nor, so far as I am aware, precisely what rocks are included by this term "Lydenburg beds."

There is no doubt that there are two great groups of volcanic rocks between the Vaal River and the Langeberg, one of which, the Pniel and Vetberg group of Stow, lies below the Campbell Rand limestones and in part, at least, below the quartzites, etc., under the limestones, and the other above the Griqua Town beds.

The Ongeluk series forms seven distinct areas in Hay; all of these are synclinal basins, and will be considered separately for convenience.

The rocks are lavas, breccias, fine-grained tuffs, and a few intercalated layers of brilliant red jaspers.

In the areas marked as covered with the Ongeluk series in the map accompanying this paper there are some masses of intrusive igneous rocks. The separation of these from the intrusive rocks presented such difficulty in the field that it was not attempted. A detailed survey, occupying a long time, would have been necessary to map out the breccias and tuffs as distinct from the lavas, for the two kinds of rock make very similar outcrops, and the finer grained lavas are difficult to distinguish in the field from some of the tuffs; this work, therefore, was left unfinished.

1. *The Ongeluk-Witwater Basin.*

This large synclinal area of volcanic rocks stretches from Melk Vley and Ganna Laagte, south of Witwater, to beyond the Barkly West boundary, north-east of Groen Water, a distance of over 63 miles, and from the west side of the Asbestos Mountains, north of Kievets Kloof, the average width is about 18 miles. Owing to the bend south of Postmasburg, the general direction of the synclinal axis is north-east.

Traverses from the sedimentary rocks of the Griqua Town series on to this syncline were made from the south (Claradale to Witwater; from the west (Eden to Poortje; Matsap to Ongeluk; Wolhaar's Kop to Bosch Poort; Postmasburg to Tiger Kloof); and from the east (near Taaibosch Fontein (see fig. 4), Moss Fontein, and the north-north-east along the boundary between the two as far as Peiser's mine).

In every case the Griqua Town rocks dip towards the volcanics, though there is at all the localities mentioned a strip of sand which covers the passage beds to a greater or less extent.

[1] Geological Sketch Map of South Africa, Melbourne, 1887. From the map itself "Lydenburg beds" include everything from the Campbell Rand to the Matsap series, excepting the Ongeluk beds.

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It is found that the lowest members of the volcanic group are especially liable to give rise to hollows, flat valleys, in which reddish sandy soil accumulates. The volcanic rocks usually rise as escarpments at a distance of from one to two miles from the uppermost beds of the Griqua Town series. The dips of the latter are rarely as much as 10°, and on reaching the volcanic beds their dips are usually found to be less, though from the nature of the lavas and tuffs it is not easy to observe the dip accurately. The lavas, etc., are thick bedded, and it is from the step-like declivities of the escarpments that their stratigraphical position is arrived at. This feature is well seen in the hills made of the volcanic rocks south-west of Peiser's mine as far as Smit's Dam (O. 3), on Melk Vley, Van Nel's Dam, and the hills stretching from Bosch Kloof north-eastwards to Tiger Kloof.

So far as the evidence yet obtained bears on the question, the Ongeluk volcanic series lies conformably upon the Griqua Town beds in Hay. This conclusion is based on the fact that wherever the rocks immediately below the volcanics are visible they are either the glacial beds or ferruginous rocks, cherts, and thin limestones, *i.e.*, beds known to belong to the uppermost part of the Griqua Town series. There are, of course, many tracts of country where the succession cannot be ascertained for want of outcrops, but the occurrence of the uppermost Griqua Town beds dipping towards the Ongeluk series was so frequently observed in the case not only of the Ongeluk-Witwater syncline, but in those of the six other synclines as well, that I have no doubt that the above conclusion is correct.

At one boundary only is there contradictory evidence, along the western side of the Lucas Dam syncline the uppermost Griqua Town beds are reversed, and they dip westwards away from the volcanics at a high angle. This is certainly an overturned succession due to folding subsequent to the out-pouring of the Ongeluk lavas, possibly, also, subsequent to the deposition of the Matsap beds.

From Stow's map[1] it would be thought that the volcanic beds lie against the Campbell Rand limestones between Gasip and Ongeluk, but this is not the case; the volcanic rocks are nearly 20 miles wide across their strike near Gasip, and they extend many miles north of that place. Stow evidently went round the north end of the syncline without knowing that the volcanic rocks existed so far north as Tiger Kloof. From the hill-tops at Tiger Kop, Groen Water, and north-east of Peiser's mine I saw a ridge, which is evidently continuous with the hills made of the Griqua Town series on Doorn Fontein (Barkly West), stretching round to join the Asbestos Mountains somewhere north-east of Vogelstruis Dam, but I could not locate the ridge on the map, and that part of the country has not yet been examined.

[1] Stow, *loc. cit.*. Pl. XXXV.

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The lavas in the Ongeluk syncline are chiefly compact, fine-grained, blue-green rocks, in which one can make out little or no structure in the hand-specimen; small black flecks, which are often seen, resemble the flecks in the lavas of the Juanana syncline described below, and are doubtless the same mineral, bastite pseudomorphs after enstatite. More obviously crystalline lavas occur in the Ongeluk hills and south of Tiger Kop.

Amygdaloidal lavas are seldom met with in the Ongeluk syncline; the only places at which I saw outcrops of this type were on O. 78 (near Waterboer's Dam), on Vlak Plaats and Blauwbosch Kuil, and Kruger's Dam.

Breccias occur more frequently than amygdaloids; they are bluish-green or pale greenish grey rocks, with angular pieces of compact lava in them. The pale green rocks probably owe their colour to epidote, a decomposition product of certain minerals in the lava fragments and the comminuted lava of the matrix. Outcrops of breccia were seen on Kruger's Dam, Ongeluk, at several places between Waterboer's Dam and the western border of the syncline, on Blauwbosch Kuil and Vlak Plaats, and on Bosch Poort.

There are many outcrops of compact rocks which show no sign of crystalline structure, and which are probably fine-grained tuffs. These have not yet been examined under the microscope, nor have the lavas of the Ongeluk syncline.

The breccias and tuff-like rocks are not confined to any one horizon in the series. Those on the west side of Waterboer's Dam are near the base, and those on Ongeluk must be high up in the group.

A very remarkable rock is the brilliant red jasper which occurs in beds intercalated with the lavas from Van Nel's Dam through Waterboer's Dam, Kain's Vlakte, and Bonnet Fontein to Sunnyside. This rock is rarely seen in outcrops, though fragments of it are found in gravels in very many parts of Hay, and also east of the district. There is no jasper in the Griqua Town series known to me which has such a brilliant colour. It is unfortunately a brittle rock, though very hard, or it would be of use as an ornamental stone. Along certain lines of country, one of which has been stated above, while another runs from Taaibosch Draai, below the escarpment east of Ongeluk and past Peiser's Mine, pieces of this jasper are seen on the veld more frequently than elsewhere, and approximately mark the position of the rock below the soil.

On Waterboer's Dam the red jasper has been opened up by cuttings; it is interbedded with greenish chert and a diabasic rock. At this locality there is a fault on the west side of the jasper opened up, and the latter has an almost vertical dip. One outcrop strikes E. 15° N., quite an abnormal direction for this area, and is isolated from others to the north and south by faults.

Thin sections of this jasper are not yet available.

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It appears to represent a deposit laid down on a floor of lava and covered by later flows of lava.

As mentioned previously, there are rocks associated with the Ongeluk volcanic series that are probably intrusive. A mass of probably holocrystalline diabase occupies a wide area on the east side of the volcanic rocks between Taaibosch Puts and Moss Fontein. In this mass is situated the dyke-like body of basic breccia from which diamonds are obtained at Peiser's Mine. The excavations at the mine are the only places where one can get a good section through the diabase, which is exposed for rather over 60 feet. Though much decomposed within 30 feet or so of the breccia, the rock is well enough preserved to allow one to ascertain that there are no divisional plains within the exposed thickness to represent surfaces between successive flows of lava. Fresh rock from the same mass was got from a well further from the breccia, but it has not yet been examined in thin section.

From the facts known at present, it is impossible to be certain of the nature of this diabase, though the appearance of the rock in the mine cuttings inclines me to the opinion that it is intrusive.

A tongue of probably similar rock lies east of the fault on Taaibosch Fontein. From the field evidence, this rock may be either a lava flow or an intrusion; I could not decide the point.

The only rocks from this great syncline that have yet been cut for microscopic examination are two varieties of diabase from Witwater. In one of these (1,448) there is much colourless augite in elongated sections, often twinned once along the orthopinacoid and having many lines of dusty inclusions parallel to the base; the augite is partly changed to chlorite; it occasionally encloses parts of the ground mass, but typical ophitic structure is not seen. The felspar has almost entirely suffered change into aggregates of other minerals, amongst which epidote, chlorite, quartz, and colourless hornblende are recognisable. There may be patches of felspar left amongst these aggregates, but they do not show twinning. No calcite is seen amongst the alteration products. There is a fair amount of original quartz present, some of it intergrown with what was once felspar. Leucoxene and iron ores are present in small amount. The original nature of the ground mass in this rock is obliterated, but it is probable that the rock was not holocrystalline, in the sense that a typical dolerite of the Karroo region is. Another section (1,447), taken from a green rock, is still further altered; the most conspicuous constituent is epidote; augite is represented by a few small remnants, the most of it has changed, apparently into epidote. There is much quartz and felspar in the ground mass in irregular patches of which the boundaries do not coincide with the outlines of the original felspars, as indicated by streaks of dusty inclusions. There is more leucoxene in this rock than in the last.

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The maximum thickness of the volcanic rocks in the great syncline must be very considerable, probably over 1,000 feet; but the difficulty of getting a series of observations for dip makes an approach to exactness impossible. It is likely, also, that there are several strike faults within the area corresponding to the Taaibosch fault. One such fault brings in a considerable thickness of the Griqua Town beds on Waterboer's Dam and Lake Warren; the thin limestones, ferruginous rocks, and cherts are exposed, but the glacial conglomerate was not seen; it is probably under the sand on the west side of the ridge.

2. *The Juanana Syncline.*

This is a much smaller area of volcanic rocks, but in many respects its small size is compensated by other points of interest, the clear evidence of its relation to the Griqua Town series and the repeated intercalation of breccias and tuffs with the lavas. The length of the syncline is about eight miles. and its greatest width little over three.

The north end of the syncline is a great rounded mass, which rises to form a high hill, on which is placed the beacon common to Kama, Omdraai, and Juanana. The highest sedimentary rocks which I saw on approaching the hill from the east are hard reddish jaspery rocks, interbedded with heavy blue slates; a considerable interval of covered ground comes between these outcrops and the lowest of the volcanic group, which is a very compact blue-green rock, with black flecks in it; the black flecks are rarely a millimeter in length. Under the microscope, the black spots are seen to be enstatite crystals or pseudomorphs after that mineral, and the ground mass (1,442) is made of feathery aggregates of a fibrous mineral, very pale green, non-pleochroic, and usually with an extinction angle of several degrees off the length of the fibres; it gives yellowish-white tints between crossed Nicols; it seems to be more like an amphibole than any other rock-forming mineral known to me. No felspar laths nor any indication of them are visible. In amongst the feathery hornblende there is some quartz, in the form of a minute mosaic. Very small grains of epidote are also present, and in one spot this mineral has taken the place of an enstatite crystal. This rock is evidently a variety of enstatite-andesite.

Further up the hill there are grey and green compact rocks, showing no structure to the naked eye. A section through one of these (1,443) shows a very fine-grained material, in which quartz, in the form of mosaic, is the most important constituent, but with the quartz there are immense numbers of very minute, more highly refracting yellowish grains and short needles. These are too small to identify. The rock is probably an altered fine-grained tuff.

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The top of the hill is made of a bluish rock (1,444), which is less compact than the lowest lava. Under the microscope, it is seen to consist of a greatly altered ground mass, in which there are small porphyritic crystals of two kinds; one is augite in long and irregularly bounded prisms, and the other was in shorter prisms, with straighter boundaries; but it is now represented by pseudomorphs of a serpentinous mineral; the shape of the cross sections of the latter is that of the pyroxenes, and they were probably enstatite. There is still some felspar in small laths, partly decomposed. The bulk of the ground mass is made of very minute areas of more or less clear minerals, and appears to be isotropic under a low power, but under an eighth-inch objective, it splits up into the small areas mentioned.

This rock is a pyroxene-andesite, and from the appearance of rocks from other localities, it is probably a common type of lava in the Ongeluk series.

The compact green rocks with small enstatite crystals are also very widely spread in this series.

The south-western beacon of Juanana is placed on the top of another hill of lavas and tuffs. From a distance of two or three miles, the synclinal structure of this hill is very obvious; the upper beds of the Griqua Town series are seen to dip under the lavas on either side and the differences between successive lavas and tuffs or breccias is brought out by the weather, so that the hill sides show several step-like outcrops of the harder layers. The best section is afforded by the eastern slope of the hill; there the glacial beds are separated from the lowest lava flow by thin bedded reddish brown argillaceous quartzites and a spotted rock of more or less the same nature, about 30 feet thick in all. Above this quartzitic rock there lie about 500 feet of volcanic beds, as follows:—

Lava, compact enstatite-andesite	100	feet.
Coarser lava	40	„
Rather coarse breccia	15	„
Coarse lava	20	„
Breccia	25	„
Compact enstatite-andesite	80	„
Fine grained blue argillaceous rocks, probably tuffs	30	„
Lavas (1,454)	120	„
Compact enstatite-andesites	100	„
Reddish brown quartzites, etc., 30 ft Glacial conglomerate	—	
	530	feet.

A section (1454) of a rather blotchy looking compact blue lava, about 200 feet above the base of the series, shows altered crystals of a pyroxene set in a matrix that was once glassy, and

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which contains long laths of felspar, replaced by a quartz mosaic and other transparent minerals, and accompanied by long feathery growths of colourless hornblende. The rock was evidently of the same type as that from which section No. 1,442 was taken, but the remains of a glass base are more abundant and the former presence of felspar is more distinct. The pseudomorphs after the pyroxene are either serpentine, quartz, or partly made of each of these minerals. The original nature of the crystals is evident from the characteristic shapes of the transverse sections.

No amygdaloid was seen in place, but the frequency of large fragments of the rock along parts of the slopes proves its existence. A section (1,455) from one of these fragments shows a large amount of augite, partly fresh, but mostly altered to a greenish granular substance, lying in a quartz and perhaps felspar ground mass; much of the greenish substance looks like chalcedonic silica coloured by chlorite.

There is much sphene in small grains in this rock. Chalcedony, calcite, and a chloritic mineral occur in the amygdales.

On the south-east side of the syncline there is a fault which repeats the bottom of the volcanic group and the top of the Griqua Town series. It is very similar to the Taaibosch fault, and has the downthrow side on the east.

No outcrops of the bright red jasper were seen in the Juanana syncline, but on the eastern side, about two miles from the south end, there is a group of cherts, a few feet thick, in the lavas. A thin section of this chert shows that there also are small patches of calcite and small flecks of a chloritic mineral. The rock in situ has the appearance of having been interbedded with the lavas during their formation, and the characters seen under the microscope are consistent with this view, for it does not appear to be a silicified tuff or other rock of volcanic origin.

3. *The Abram's Dam Syncline.*

The whole of this syncline has not been examined, and its northern and southern limits are at present unknown; its length from N.N.E. to S.S.W. is certainly over 16 miles, and its width, from Waterkop to Middel Kop, about 11 miles. The eastern limb of the syncline forms a well marked escarpment, visible from a long distance, and distinguishable from the hills of Griqua Town beds to the east by its colour and shape.

At the base of the series on the farms from Koodoos Dell to Namiecaap there are compact lavas, below which the highest visible rocks of the Griqua Town series are ferruginous beds, with cherts and limestones. A well-marked line of valleys on Eland, Stinkwater, Abram's Dam, and Namiecaap, running parallel with the strike of the beds, is caused by the presence of a rather thick belt of flaggy green tuffs, which weather more

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readily than the lavas above and below; they dip westwards at a low angle. West of these green flaggy beds there is a considerable thickness of lava, probably some 300 feet, below a thick belt of volcanic breccia on the farm Klip Bak. For some five miles westwards from these breccias the country is covered with deep sand, but there is a slight ridge of lava on the farms Zwart Veld and Naauwkop, a few miles south of the road. The beds in the middle of the syncline lie at very low angles, as can be seen on the Klip Bak outcrops. Towards the west side of Middel Kop and Zwart Veld the breccias are again seen, greenish, coarse rocks, with angular fragments of lava, like the Klip Bak outcrops; they are underlaid by a thin band of compact lavas, which rest upon the Griqua Town beds; the uppermost outcrops of the latter are again ferruginous cherty rocks, with limestone beds.

No microscopical work has been done on the rocks of the Abram's Dam syncline, but the lavas and breccias are evidently of the same general type as those in the Ongeluk and Juanana synclines.

4. *The Paarde Vley Syncline.*

This volcanic area is separated from Abraham's Dam syncline by an anticline of Griqua Town beds. It is about nine miles long and three wide at the broadest part. The angles of dip at the periphery are rather higher than those round the other synclines. The greater part of this area is made of compact blue lavas, with the small dark crystals of enstatite or minerals which replace it; on the north of Koegas Puts there is a large mass of breccia, apparently lying above the highest exposed lavas.

5. *The Leelyks Dam Syncline.*

This comprises a small area of volcanic rocks on Leelyks Dam, Kwakwas, Gras Gat, and Witberg. It is composed of lavas, amygdaloidal and compact, and breccias. A thin section through a breccia (1460) from this area shows it to be made of fragments of vesicular lava set in a matrix which contains epidote and much quartz. One lava fragment is a rock made up chiefly of small felspar laths belonging to the oligoclase-andesine group, set in an indeterminate base; there is no visible ferro-magnesian constitutent in this fragment, which differs considerably from the few lavas of this group that have been examined in thin section.

The north end of this syncline is probably concealed under the sand east of Piljaar's Poort. Round the east, south, and south-west sides the Griqua Town beds dip under it; on the west side it is bounded by the ridge of Matsap beds which runs

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south-south-west through Piljaar's Poort. I did not find a clear section through the junction of the two rocks, but the general course of the boundary, taken together with the higher position and westward dip of the Matsap bed, left no doubt in my mind that the latter lie unconformably upon the volcanic beds.

6. *The Lucas Dam Syncline.*

There is an area of volcanic rocks which stretches from Floradale past Lucas Dam into the Vryburg Division, and it is certainly more than 20 miles long. The ridge on which Wolhaar's Kop stands is made of Griqua Town beds, dipping, on the western side, towards the volcanic rocks; and in the long ridge of the upper part of the Griqua Town beds on the west side of the volcanic rocks the former dip away from the latter, so the western side is overturned.

The volcanic rocks themselves make but few outcrops from Lucas Dam southwards, but all the wells, of which there are three known to me, in that distance of about fifteen miles, reveal the presence of the lavas under the soil, and at Floradale and Lucas Dam outcrops are met with. About five miles north of Lucas Dam the volcanic rocks rise into a hill of same general appearance as those in the Juanana syncline. An inlier of the Griqua Town beds, faulted on the east against lavas (which are on the downthrow side), occurs on Lucas Dam.

It is possible that this area of lavas may be directly connected with the Ongeluk-Witwater syncline by the north-westward projection of the latter on the farm Sunnyside; but direct evidence of this is wanting. There may also be a connection, concealed by the soil, between the volcanic rocks just north of Lucas Dam and the Vlak Fontein syncline.

7. *The Vlak Fontein Syncline.*

This is the south end of a larger area in the Vryburg Division. It is partly, at least, separated from the volcanic hills north of Lucas Dam by an anticline of the Griqua Town beds, while to the east there is the faulted country near Paling ridge (see fig. 5). The effect of the faults is to bring the Campbell Rand limestone nearer the volcanic rocks on the surface than they would be if the district were free from faults. The intervening ground, so far as two traverses gave evidence, shows no outcrops from beneath the sand and calcareous tufa over a width of nearly two miles.

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: . mparison with the Pniel Volcanic Rocks.

There is as yet insufficient material on which to base a satisfactory comparison with the volcanic rocks below the Campbell Rand limestone and the Black Reef. In the field there is often a considerable resemblance between them, but so far as the present survey has gone the more acid rocks which occur abundantly in the Pniel series at Villet's Kuil, Bidouw's Kuil, and T'Kuip, and also in the Pniel and Kimberley area, are not matched by similar lavas and breccias in the Ongeluk group; this is especially the case with the acid porphyries which are conspicuously developed along the Brak River (Hope Town), and have not been met with in the Hay Division.

Amygdaloidal lavas are much more abundant in the Pniel group than in the Ongeluk.

Hitherto the only interbedded fragmental rocks noticed amongst the Ongeluk lavas have been breccias, green tuffs, cherts and bright red jasper. No cherts or jaspers have been recorded from the Pniel group,[1] but in the Kimberley shafts thick quartzites and shales are certainly interbedded with the igneous rocks.

Inter-relation of the Synclines in Hay.

From the general similarity of their contents and the high scarped edges of synclines, it would be gathered that the Ongeluk volcanic rocks once formed a continuous area, covering a very large part of the Hay Division.

At present there is no definite evidence of the position of large vents

[1] Cherts have been found in the Zoetlief beds of Vryburg, which probably belong to the Ventersdorp beds, the group that also probably includes the Pniel lavas and breccias. See Du Toit, below.

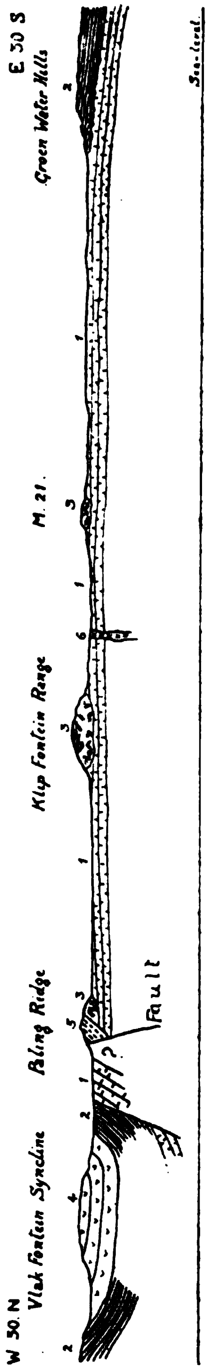

FIG. 5.—Section through Blink Klip Field Cornetcy. 1. Campbell Rand series. 2. Griqua Town series. 3. Blink Klip Breccia. 4. Ongeluk volcanic series. 5. Matsap beds. 6. Dolerite or diabase dyke. Distance, 10½ miles; horizontal to vertical scale, 1:2.

from which the lavas and breccias were ejected. While traversing an area of coarse breccia on Klip Brak and another on Leelyks Dam, I thought that these breccias might be the contents of a throat, but at Klip Bak there were signs of stratification. A much more detailed survey than I could make last season will be necessary to find out the probable sources of the lavas and breccias.

Under the heading of "Intrusions" there will be found an account of some masses of diabase, which present some resemblance to the coarser varieties of the Ongeluk lavas, but which are intrusive amongst the surrounding rocks. Some of these may have been formed in connection with the volcanic activity during the Ongeluk period.

THE MATSAP SERIES.[1]

The Matsap beds form three distinct groups of ridges in the Hay Division, of which the Langebergen are the most important.

This series consists of quartzites and grits, with occasional thin layers of conglomerate. There is one area of a peculiar ferruginous conglomerate in the Matsap ridge. The general colour of the rocks is purplish grey, and in their typical form they are distinguishable from all other quartzitic rocks known to me from Cape Colony. Associated with the typical Matsap beds of the Langeberg there are others, whose relation to the rest of the formations is still a matter of doubt, but as they are so closely connected with the Langeberg, I have marked them on the map published with this Report with the same stippling as the Matsap beds, and their relations are discussed below.

The three groups of hills formed by the Matsap beds are :—(1) The Matsap ridge; (2) The Langebergen, etc.; (3) The Paling hills.

1. *The Matsap Ridge.*

This range of hills made of the Matsap beds is about fourteen miles long, and at the most rather over two wide. It is cut through by the dry river bed near Matsap, and again by the dry channel on Zaai Plaats.

It is only at the extreme south end of the ridge that the relation of the rocks to other formations can be made out. The beacon common to Paauw Vley, Cairn Toul, Nek, and Koodoos Kloof stands on the top of the south end at a height of 500 feet above the flat ground on Nek and Koodoos Kloof. The Matsap grits and quartzites form the uppermost 200 feet or so of the hill, while below them massive haematitic rocks, passing below

[1] Dr. Siegfried Passarge uses the term "Langeberg beds" ("Kalahari," 1904, p. 70) in place of "Matsap beds" on account of the great importance of the Langeberg range as a feature in the land, but there is insufficient reason to change the name, and in view of the existence of several ranges called "Langeberg" in different parts of the Colony that term is a bad one

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into banded white and red cherts and belonging to the upper part of the Griqua Town beds, crop out round the west, south, and east sides of the hill. The actual junction is hidden under fallen debris, but the low dips of the Matsap beds towards the axis of the ridge on either side, for at least four miles north of the south end, show that the southern part of the ridge is a syncline of Matsap beds resting upon haematitic rocks of the Griqua Town series. These haematite rocks lie just below the glacial conglomerates on the central part of Koodoos Kloof and on Water Kloof. North of Lang Kloof the structural features cannot be made out so well, because on each side of the ridge sand and alluvium cover the rocks completely for a considerable distance from the Matsap outcrops.

On Zaai Plaats the synclinal dips are seen, but the beds are considerably bent, so that the ridge is no longer a simple syncline.

On the south end of Cone and on the east side of the ridge there is a small "hoek," formed by a subsidiary anticline in the Matsap beds, through which the haematitic beds of the Griqua Town series protrude, owing to the denudation of the crest of the anticline.

At Matsap itself the exposed part of the ridge is an anticline. The sections along the sides of the poort show the rocks dipping towards E. 40° S. at about 40° on the east side; further north they dip in the more usual direction of E. 20° S. an angles of about 70°; on the western side of the ridge the dips are less clearly seen, but they are towards W.N.W. at lower angles than the eastern dips.

The north end of the ridge slopes down under the great alluvial flats on O. 81.

The bulk of the Matsap beds of this area are purplish quartzites and grits, containing pebbles in thin layers or scattered through the rock at wide intervals. The pebbles are of white quartz, black and red jaspery magnetic rocks, and brown jaspers, but the brown jasper pebbles are not as often seen as the red. About a mile and a half north of the poort a prospecting shaft has been sunk on a bed of quartzitic conglomerate containing pyrites. The pebbles in this rock are quartz and quartzite, and black and red jaspery rocks. The results were apparently unfavourable. The superficial resemblance to some of the gold-bearing conglomerate of the Rand evidently led to the prospecting.

On the south side of the poort near Matsap there is a remarkable conglomerate exposed along the axis of the denuded anticline near the middle of the ridge. The matrix of the conglomerate is a very ferruginous reddish, fine-grained rock, which weathers with a brown coat; the pebbles are of all sizes up to

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12 inches in length; they are mostly well rounded, water-worn pieces of red and brown magnetic jaspers of the types so common in the Griqua Town beds of Hay. The conglomerate is roughly bedded, and evidently lies conformably below the purple quartzitic beds which are exposed on the east, south, and west sides of the area occupied by it. The rock immediately below the ferruginous conglomerate is not seen. The whole thickness of ferruginous conglomerate exposed is about 15 feet. Nothing like this conglomerate has been noticed elsewhere in the Hay Division; in the Langebergen and the Paling ridge no rocks with a highly ferruginous matrix was seen; these two groups of hills are made of precisely the same type of quartzite and grit, with pebbles of quartz and jasper, as are found in the Matsap beds.

The wells dug in the flat ground east of the Matsap ridge do not reach bed-rock, so the distance through which the Matsap beds extend towards the east is unknown; the nearest outcrops of the Griqua Town beds are about three miles distant.

2. *The Langebergen.*

Under this term I include all the ridges made chiefly of purplish quartzites stretching in a north-north-easterly direction from the neighbourhood of the Orange River below Pypwater to Andries Fontein and the Vryburg border, a distance of about 80 miles; they extend beyond the border for a considerable distance.

The direction of the strike of the beds varies; near the Orange River it is about N. 28° E., northwards from Baken Kop it is N. 24° E., while north of Paarde Kloof the strike in the main range is about N. 16° E., and that of the subsidiary ranges to the east, made of rock of which the relations are not yet satisfactorily determined, is near N. 5° E. It is interesting to note that the strike of the Ezel Rand beds (also of Matsap age) south of the Orange River in Prieska is on the average N. 35° E. I was unfortunately unable to complete the examination of the ground between Ezel Rand and Zeekoe Baarts Nek (O. 307), an area which will be surveyed this year (1906).

It was only at the extreme south end of the Piljaar's Poort hills that I found exposures of the Griqua Town or other beds at the base of the hills made of the Matsap beds. The Piljaar's Poort hills bifurcate on the western farm of the two called Witberg; the structure of the hills is there clearly synclinal, closely resembling the south end of the Matsap ridge. On the eastern side of the hills on Witberg the Matsap beds rest upon the Ongeluk volcanic series of the Leelyks Dam syncline.

On the small hill bearing the beacon common to Piljaar's Poort, Witberg, and Stilverlaats, the Matsap beds are in contact with the Griqua Town beds along a line of fault. The

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haematitic rocks of the latter series dip at high angles westwards, and the Matsap beds are highly inclined towards the east. The Matsap beds are purplish quartzites, with many pebbles, amongst which red and black banded jaspers are the most conspicuous.

A dry river bed, called the Matsap Loop, divides the Langeberg proper from the hills made of the same rock to the south. North of the Loop the Langeberg summits reach a height of about 1,600 feet above the flats, to the east of them, and usually there is a smaller difference of level above the Kalahari surface to the west. As Stow pointed out, the contours of the Langebergen are rounded, north of the Pad Kloof Pass there are considerable stretches of level ground on the top; but there are nowhere peaked summits on the main range. In contrast to this range, the eastern ranges, between Andries Fontein and Dunmurray on the west and Lucas Dam on the east, have some sharp peaks on them, probably due to the presence of thick shaly bands between the quartzites.

In the neighbourhood of Bakens Kop at the south end of the main range the rocks are thrown into two chief anticlines and two synclines; the dips are usually above 40°.

The Pad Kloof Pass affords a good section, and here the beds are much folded; on the eastern side of the range the dips are towards north of west at every place where the observation was made between the extreme south on Witberg and the Andries Fontein beacon hill; but in the western half of the range there are many curves, bold rounded troughs, and arches of a very different character from the sharp, but small bends in the Griqua Town series to the east. At one place on a hillside about a mile north of the west entrance to Pad Kloof there is a syncline with both limbs inclined eastwards. The figure in Stow's paper[1] gives a correct impression of the type of folding in the Langeberg, but the quartzites are carried too far eastwards towards Potgieter's.

A striking feature in the Langeberg is the uniform character of the rock; at places slightly sericitic beds are seen, and at others the rock is rather more deeply weathered than usual, but one finds the same kind of purplish gritty, coarse quartzites, with jasper and quartz pebbles throughout.

The eastern hills, made of rocks whose relations are doubtful, extend from the east side of Bergenaar's Pad to the Vryburg border, a distance of 20 miles. They form three distinct ranges, in all of which the beds dip at a very high angle towards the west; in the easternmost ridge there are some sharp contortions, but these do not materially affect the general statement. Unlike the typical Matsap beds, these rocks include several thick bands of micaceous brown shaly rocks, and there are at least two rather persistent beds of conglomerate in them, which do not

[1] Stow, Q. J. G. S. XXX. Pl. XXXIX. fig. 5.

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contain jasper pebbles. These conglomerates have been prospected for gold, but the results have not been made known. They are quartzitic rocks, with quartz pebbles and some pyrites in the matrix; the pebbles are abundant, well rounded, and reach a length of four inches; the thickness of the exposed bed of conglomerate is about two feet. The absence of jasper pebbles from these eastern rocks perhaps gives one a biassed opinion as to their relation to the Matsap beds, and the absence may be merely due to lack of observations, for I found a small piece of quartzite with a jasper pebble in it near the path across the boundary ridge on Lucas Dam; it was a loose piece, and may have got there accidentally. On the east of these ridges, between them and the Griqua Town ridge on Lucas Dam, there is a sandy valley in which there are shallow holes in the underlying rock, a purple talcose slate, unlike any other rock in the district. There may possible be an overthrust fault along the eastern side of the quartzite and shale ridges; the Griqua Town and Ongeluk beds are certainly overfolded towards the west in the immediate neighbourhood; but more work must be done in this region before a useful opinion as to the relation of the quartzite, conglomerates and shales can be given. In colour much of the quartzite is purple, like the usual Matsap beds, but grey, reddish, and brown rocks are not uncommon.

3. *The Paling Ridge.*

This is a ridge made of Matsap beds dipping about N. 20° W. at various angles from 10° to 40°, but the trend of the ridge is nearly north and south, and is determined by the course of the fault on its western side, along which the Matsap beds are thrown down against the Campbell Rand beds on the south and the top of the Griqua Town beds further north. The rocks are purple quartzites and grits, containing bits of brown and red jasper. They rest unconformably upon the Blink Klip breccias on their eastern side. These hills are continued into Vryburg.

Some of the Matsap beds on this ridge make good flagstones, which are used in the farmhouses in the neighbourhood.

General Relations of the Matsap Series.

The evidence afforded by the position of these beds at the south end of the Matsap ridge and at the south end of the Piljaar's Poort ridge is a strong confirmation of the view adopted in 1899 that the Matsap beds of Ezel Rand are later than the Griqua Town series; but we have also to say now that they are later than the Ongeluk volcanic beds. From the main ridge of the Langebergen no such direct evidence is as yet known.

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Then, again, we have the fact that pieces of red and brown jasper, supposed to have come from the Griqua Town beds, occur in the Matsap beds. These pebbles have not yet been examined microscopically, so their origin cannot be discussed with good effect at present, but it should be noted that jaspers and magnetic rocks occur in two formations in South Africa older than the Griqua Town beds, the Witwatersrand beds and the still older schists of Swaziland and of the Vryburg and Mafeking Divisions. This question of the origin of the jasper pebbles was very forcibly put before me during the field-work of last year by the fact that although the thick Ongeluk volcanic series is undoubtedly of later age than the Griqua Town beds, and, if the still later age of the Matsap beds be a true inference, although the volcanic rocks must have occupied a wider area during Matsap times than they do to-day, not a single pebble or other fragment of the lavas or breccias could be found in the Matsap beds. Now, considering that these volcanic rocks, apparently suitable for the supply of pebbles, as the Dwyka and recent gravels prove, did not contribute towards the material which went to form the Matsap beds in Hay, how could the underlying Griqua Town beds in that district do so?

A thin section (1461) of a grit from the Matsap beds at Piljaar's Poort shows that the grains of quartz are remarkably round in section. Their outlines are clearly indicated by films of dusty matter, and the interstices are filled with quartz.

As to the correlation of the Matsap beds with rocks in other parts of South Africa, I have no new information of importance. It has been suggested that they are not only the equivalents of the Waterberg sandstones of the Transvaal, but also of the Table Mountain sandstone of the south of Cape Colony and Natal.[1] Until palæontological evidence is obtained, objections to this view, that great disturbances and denudation must have gone on in the north during Bokkeveld-Witteberg times, and that during this interval the Matsap beds must have been converted into quartzites and closely folded, though under circumstances which exclude any but the thinnest cover, seem to me more weighty than the doubtful advantage of an uncertain correlation.

THE DWYKA SERIES.

These rocks occupy a very small part of our district. In the tongue of land enclosed by the bend of the Orange River near Prieska village there is a continuation of the large area of Dwyka beds which lies south and east of the village. The beds are boulder-beds of the nature of till, thin conglomerates and shales. Their presence is indicated by the numerous boulders

[1] Passarge, "Die Kalahari," 1904, p. 70. Hatch and Corstorphine, "Geology of South Africa," 1905, p. 309. Passarge correlates them, in preference, with the Cango and Ibiquas conglomerates.

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of various kinds of rock, often flattened and striated on one or more sides, which lie in the surface soil. Actual exposures are only seen in some of the ravines and are small, but looking eastwards from the Krantz Fontein hills I could see fine cliffs cut in the Dwyka beds further up the river than my work was carried. A ridge of Griqua Town beds projects through the Dwyka on Fonteinje and Spitzkop, and a small hill of the same formation does so on the outspan (Stof Bakkies). The Dwyka here fills up an old strike valley in the Griqua Town beds, and the modern drainage lines traverse the old valley nearly at right angles.

There is an outlier of the Dwyka on the limestones of Enkelde Wilgeboom.

The most abundant rocks in the form of boulders in the till and conglomerates are lavas, compact and amygdaloidal; they are mostly from the Pniel volcanic group; after these limestones or dolomites from the Campbell Rand and various rocks from the Griqua Town beds are most frequently seen; granites and gneiss are not uncommon.

No striated floors were observed in this area.

An interesting outlier of Dwyka was found on the farm Piljaar's Poort in the bifurcated end of one of the Langeberg group of hills. It appears to lie in a rock-basin, though there may possibly be a connection under the sand westwards with a larger area of Dwyka along the Orange River, but none has been noticed there as yet. If the hollow is a true rock-basin it will be very difficult or impossible to determine its nature or origin, for the rocks are not well exposed. A well about 60 feet deep has been sunk in the outlier without reaching the bottom. The matrix of the Dwyka is a gravelly grit; no mudstone was passed through in the well. The boulders have the characteric shapes and striations; the most abundant rocks are Matsap quartzites, jaspers, etc., from the Griqua Town beds, volcanic rocks, both lavas and breccias, felspar porphyries, and more basic igneous rocks, which probably came from dykes or other intrusions.

On the eastern side of the Campbell Rand, below the escarpment, the Dwyka covers a wide area, but its limits have not been traced. On the location ground, N.W. 71 and N.W. 2, quartz-porphyries and lavas, with red chalcedony amygdales, are very conspicuous in the Dwyka, and there are also some quartzites, with chert pebbles.

On Vervanhier (Barkly West) there are two wells sunk on black shales with thin, hard ferruginous layers, probably Upper Dwyka shales.

On the main road to Barkly West from Delport's Hope there are good exposures of the lowest part of the till-like Dwyka still adhering to scored surfaces of the Pniel volcanic group. The best examples are on the eastern side of H.V. 47, where the general trend of the striae on the volcanic rocks is W. 36° S.

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South of the bridge across the Vaal River at Barkly there are roadside quarries in thin bedded, greenish shales, associated with Dwyka till; some of these shales contain striated boulders of volcanic rocks and granite.

A well exposed striated floor is to be seen in a ravine leading to the Vaal River not far from The Bend; the striae run W. 46° S. and W. 60° S. The till rests upon the floor at several spots along the course of the ravine.

Intrusive Rocks.

There are many bodies of intrusive igneous rocks in the Hay Division; they may be conveniently divided into three groups: (1) Diabase rocks, which have a similar appearance to the coarser lavas of the Ongeluk series; (2) more basic rocks of several types; (3) Dolerite of the Karroo type.

It is to be remarked that no intrusions of acid rocks, such as granite or quartz porphyry, occur in this area.

The following account is rather slight, because the thin sections of many of the rocks have not yet arrived.

1. *Diabasic Rocks.*

These form three large masses near Niekerk's Hope; two of them are dyke-like in form, and trend nearly north and south on O. 355 and O. 368; the third is an irregularly shaped mass, on which the village of Niekerk's Hope stands.

A thin section from the Niekerk's Hope diabase (1441) shows that the felspar is very much decomposed; it formed intergrowths with quartz in the ground mass, but its original characters are no longer preserved. The augite is much less altered; it occurs in ill-developed prisms, with basal striations, it is frequently twinned on the ortho-pinacoid, and it has a tendency towards ophitic structure, which, however, is not nearly so well developed as in the thick intrusions of the Karroo; it has in places changed to pale green fibrous hornblende (uralite). There is a fair amount of leucoxene in the rock, and other alteration products are epidote and zoisite. These three masses are intruded into the Griqua Town beds.

On Balloch there is a rather broad intrusion, also in the Griqua Town beds. In thin section (1445) this rock is of much the same type as the Niekerk's Hope diabase, but there is less quartz, and the ophitic arrangement of the augites round the decomposed felspars is more marked.

The contact of this diabase with the Griqua Town beds is exposed in a cutting made for the purpose of opening up a galena lode, and the effect of the igneous upon the sedimentary rock is great. The sedimentary rock was a ferruginous cherty or quartzitic material; but whether at the time of the intrusion

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the alterations had taken place which changed the bulk of the Griqua Town beds in this neighbourhood into jaspers and heavy rocks containing crocidolite is not known. The rock within a few inches of the diabase (1446) is now made of a base of quartz, with innumerable flakes or fibres of actinolitic hornblende set in it, and an occasional fibrous plate of crocidolite. The presence of actinolite can be safely attributed to the igneous intrusion, for the mineral has not been observed in the jaspers, etc., of the Griqua Town series, but the production of crocidolite must be assigned to the causes to which it is due elsewhere in the district. These causes are not yet discovered, but they cannot be igneous intrusions. In parts of slide (1446) the actinolite is seen to be added to the crocidolite, in such a way that their long axes lie in the same direction; in ordinary light the whole plate seems to be one individual stained greenish-blue in the middle, but between crossed Nicols the boundary between the two minerals is found to be sharp, and is made obvious by the higher extinction angle of the crocidolite.

On the farm Oudfontein there is a dyke of diabase cutting through the Griqua Town beds in a north-westerly direction, and on the farm Juanana a similar rock traverses the Ongeluk volcanic beds for a short distance. I took both these outcrops for Karroo dolerite in the field, but an examination of the Oudfontein dyke in section (1451) showed that it probably belongs to the pre-Karroo intrusions. It is of the same general type as the Niekerk's Hope and Balloch rocks, but here the augite has suffered much more change than the felspar. There is no ophitic arrangement, both the felspar (an acid labradorite) and the augite occur in ill-developed long crystals, with the interstices filled with felspar and a very little quartz.

It has already been mentioned that some of the diabase-like rocks associated with the Ongeluk series, *e.g.*, the diabase through which the diamond-bearing breccia of Peiser's mine passes, may be intrusive, and other masses which may be of the same nature occur on Taaibosch Fontein, round the south and east sides of the Vlak Fontein syncline, and in the middle of the Ongeluk-Witwater basin at Wit Puts.

2. *More Basic Intrusions.*

In the Griqua Town beds on Piljaar's Poort there is a green fragile rock exposed in a well. The rock is evidently of igneous origin, but the dyke, which lies parallel to the strike of the Griqua Town beds, is only about twenty feet wide. In thin section (1462) the rock is seen to be very much decomposed; there are numerous more or less rectangular long sections of colourless augite, patches of which still remain, largely converted into fibrous hornblende; other crystals, now replaced by a very pale green and almost isotropic substance, may have been a

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rhombic pyroxene. No olivine pseudomorphs are visible. There is a small amount of quartz in the ground mass, but the felspar has been altered beyond recognition.

In many parts of the district wells have been sunk in very much decomposed rocks containing serpentine, but the nature of the rocks is obscure. They are only got from the wells, and they are dug out as an earthy, serpentinous mass, looking rather like "blue-ground" in a decomposed state, without the inclusions characteristic of diamond-bearing ground. Such rocks were seen on Blaauwbosch Poort, Rooi Laagte, Ganna Aar, Kameel Dam, and Kruis Pad in the Griqua Town beds; at Klip Bak, Juanana and Vlak Fontein in the Ongeluk beds, and at the Poplars O. 427 and O. 40 in the Campbell Rand limestones.

One of the least decomposed of these dykes is than on Juanana; it is exposed in a prospecting hole, where copper carbonate, limonite, and specular iron occur in a thin vein in the dyke. Its specific gravity is 3.06. In thin section (1449) this rock is seen to consist of imperfectly developed crystals of augite and pseudomorphs of another mineral, inbedded in a ground mass of fibrous minerals, of which a strongly pleochroic (blue-green parallel to the basal cleavage and orange red at right angles to it) chloritic substance is the most conspicuous. The pseudomorphs have the shape of olivine crystals, but the substance of the pseudomorph is not like that of the usual replacements of olivine, being an aggregate of highly polarizing flakes. Some brown hornblende is present, as an original constituent, and there are iron ores and grains of a strongly refracting substance not determined.

The long dyke on the Poplars and O. 40 is made of bastile pseudomorphs after enstatite imbedded in alteration products and grains of iron ores.

Along the contact with this dyke the Campbell Rand limestone is converted into a greenish hornstone-like mass, with cracks filled with chrysotile running through it.

3. *Dolerites of the Karroo Type.*

The only intrusion known to me in Hay that may belong to this group of rocks is a long dyke, traceable for over eleven miles, from near Postmasburg to beyond Klip Fontein. In the field this rock is extremely like the Karroo dykes, but it has not been examined in thin section, and after the mistake as to the nature of the Oudfontein and Juanana dykes, there is some doubt about the Postmasburg dyke.

Diamond-bearing Breccia.

The only place in the Hay Division where rocks of this kind are known to occur is the Peiser Mine on M. 57.

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The breccia fills a fissure which is of unequal width and of unknown length. So far as the mining operations had proved the position of the breccia at the time of my visit, the fissure is over 300 yards long, and about 60 wide at the widest part. At one place where the fissure is about 40 yards wide, it has a steep dip towards west-north-west. The general trend of the fissure is about N. 40° E.

Where the breccia has been removed from the walls of the enclosing rock, the latter are seen to be covered with slickensides with more or less vertical striations, pointing to the slipping down of the breccia, owing probably to consolidation of the loosely compacted mass.

The general matrix of the breccia is a greenish serpentinous substance, very soft and crumbly, and it contains large and small masses of diabase similar to that of the walls of the fissure, large and small pieces of yellow and black magnetic rocks evidently derived from the underlying Griqua Town beds, bluish crystalline limestone or dolomite from the Campbell Rand beds, small pieces of brown mica, red and brown garnet, ilmenite, and crystals and fragments of diamond.

At the time of my visit the harder, less decomposed, rock which may be expected to underlie the greenish breccia had not been reached; the core from a borehole taken from 132 feet from the surface was almost as soft as the rock obtained from the open workings at about 60 feet from the surface.[1]

Ilmenite is a comparatively scarce constituent of the breccia, and an examination of a fair amount of the material got from the sorting tables did not yield any diopside or others of the minerals that are frequently associated with the diamond-bearing and allied rocks from other parts of South Africa.

A thin section from a core (1163) from Peiser mine shows that the rock is mainly composed of alteration products, serpentine, calcite and chlorite, pseudomorphs after olivine, brown mica and grains of magnitite. Some few isotropic, highly refracting, brown octahedra of very small size may be perofskite, but this mineral is much less abundant than in the Kimberley blue-ground.

Recent Superficial Deposits.

These include gravel, sand, alluvium, and tufaceous limestone.

1. *Gravels.*

Between the Matsap ridge and the Langeberg there are gravels covering gentle slopes at various heights above the present valley bottoms, from 200 feet downwards. A gravel de-

[1] For an opportunity of examining this core and for much information I am indebted to Mr. A. Morkel, the Manager of the Peiser Mine.

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posit about 200 feet above the valley bottom was seen on the farm O. 229 south of Floradale, and the measurement was made with an anaeroid from the loop to the south-east on Valsch Pan; the figure, of course, only represents an approximate estimate.

The pebbles in these gravels are well rounded, evidently waterworn. These gravels extend over a considerable area on the east side of the Langeberg, though their boundaries have not yet been mapped out.

Near Piljaars Poort there are distinct flat-cut rock terraces, with little gravel on them, at a level of 200 feet above the Matsap Loop, where it cuts through the Langebergen.

Gravels occur at many places in river beds which have not contained running water since the area was inhabited by white men.

The broad flat valley bottoms called "loops" are usually occupied by tufaceous limestones or sand, but from wells sunk through these deposits, water-worn stones are usually thrown out. I saw coarse gravel from several wells in the Matsap Loop, from Lucas Dam in the north down as far as its passage through the Langeberg near Bingap. The depth at which the gravel is reached varies from a few feet to fifteen or twenty, but as water is got before bedrock is reached, the total depth of the superficial deposits is not ascertained.

There can be no doubt that at a time not far removed from the present, but before the Griquas came into the country, there was much running water east of the Langeberg. The river courses since then have been filled up with sand and tufa, and are gradually becoming less and less distinct. It is often impossible to recognise the river beds indicated on the Divisional map when one is actually traversing the ground, but they are more distinctly seen from the top of a hill owing to the thicker belt of bushes or low trees along their courses.

Although no water flows at the surface along these river channels, they provide courses for the underground drainage.

The rain water finds an easy passage underground through the sand or sandy soil which covers a very wide area west of the Asbestos Mountains, and when it reaches the bedrock, the greater part of it flows down towards the old main channels, and then along these towards the Orange River. The rate of flow must be slow, because the water has to make its way amongst the sandy and calcareous gravel in the old bed. The wells in these "loops" have the best reputation for withstanding droughts of any in the district; many of them have never been known to give a seriously decreased yield during a drought, though wells in the small kloofs under the Langeberg and elsewhere at a distance from the large loops dry up altogether, or yield very little water under the same conditions. Down the loop the water is usually met with at greater and greater depths.

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This is especially noticeable in the Matsap Loop below the poort at Matsap. The hard impervious Matsap beds evidently make an underground dam, so that the water immediately above it lies near the surface, while below the wells are deep. Near Bingap they are not only deep, but yield, during a drought at least, almost undrinkable water.

2. *Tufaceous Deposits or Surface Limestones.*

Calcareous tufa is found in many parts of the district. The known occurrences may be divided into two classes:—(*a*) those lying above calcareous rocks in such a way that they are probably derived from the latter and deposited on the surface in the same neighbourhood on the evaporation of water drawn to the surface of the ground by capillary attraction or other means; and (*b*) those deposits which occur in the loops and pans, and were not derived from the underlying rock.

The tufas of class (a) are met with almost everywhere on the limestone areas, such as the Kaap Plateau and the country between Groen Water and the Paling ridge. They are also found overlying the Dwyka series along the Orange River, and on the Ongeluk volcanic rocks, though in neither of the latter cases are they so abundant as in the former. These tufas are greyish or yellowish white in colour, earthy or compact, and they enclose grains of sand and clayey material. The upper surface is sometimes very hard and compact, below a varying thickness of from half an inch to three inches of this compact rock the material is usually much softer. The tufas of this kind are found anywhere, on flat ground, gently sloping ground, or even on precipitous places like the scarped edge of the Kaap Plateau, where great masses of dull earthy carbonate of lime have been deposited by water trickling down the surface from the soil on the edge of the plateau, and by water oozing out of the rocks themselves.

The tufas of class (*b*) are restricted to the valley bottoms and the variously shaped pans. They are usually earthy rocks, sometimes hard enough to be used for building, and in many cases the outer surface of portions partly separated from the bulk of the rock by wind or rain erosion are very hard.

They contain water snails and bivalves, though the latter are only got from low down in the tufa when wells are being made. At Lucas Dam Mr. Turner told me he found many of these bivalves at about 25 feet from the surface, but there were no specimens left at the time of my visit, and the well had water in it. The shells, from Mr. Turner's description, were evidently *Anodon* or *Unio*. From the tufa in the Matsap Loop below Matsap I obtained several specimens of a shell very like *Physa tropica*, Krauss, which is a living species in many parts of South Africa.

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From the tufa at the Griqua Town water cutting there were got some elephant and rhinoceros bones, but no representative collection of the bones thrown out from such excavations has been kept.

3. *Sands.*

In all the valleys west of the Asbestos Mountains there is more or less sand of a reddish or yellowish colour, and as one approaches the Langebergen, the sand increases in amount.

From wells between the Langeberg and the hills near Matsap, especially east of Baken's Kop, on Langeberg, the sand is known to be 20 feet deep in spots on the flat ground.

In the wide sandy valleys which lie east of the Langebergen north of Piljaar's Poort, there are well-marked ridges of sand traversing the valley from side to side; they rise from 10 to 50 feet above the flat ground between them, and their trend is nearly east and west. There was a fairly thick covering of bush and grass on all the sandy country during my visit, although owing to the long drought, I was informed, the veld was in a very poor condition.

At the present time the sand on the east side of the Langebergen, and also in the country immediately west of the range, cannot be moved about by the wind to any considerable extent, on account of the protection afforded by the vegetation. Supplies of red dust are undoubtedly received from the eastward, brought in by the strong east winds. The various strata exposed in the hills of Hay must yield dust and sand which is not carried down to the Orange River at the present time. The western part of the district is certainly being levelled up by the preponderance of deposition in the valleys over the amount of material carried away by wind and water.

4. *Pans.*

Pans are not abundant in the Hay district. On the Kaap Plateau and on the Asbestos Mountains the only pans seen were of quite small dimensions, 20 or 30 yards wide. They have floors of calcareous mud or tufa in the limestone areas, and brown mud floors on the Griqua Town beds.

The large pan at Matsap lies just behind the poort of the Matsap Loop, not in the direct course of the loop, but some 500 yards south (left) of it. It is separated from the low ground near the poort by a slight rise of whitish calcareous soil.

At the time of my visit the pan was dry, but water is found at a depth of eight feet. This water contains much salt, and is put into shallow iron pans when the salt separates out. The last part of the liquid is not allowed to evaporate, for it contains some nitrate, which is held to be injurious for stock. A considerable quantity of salt is thus obtained annually for use in the district.

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A sample of salt deposited in the pan itself was not obtainable, so I took for analysis a quantity of sandy salt from a heap thrown out from the iron pans, into which much sand had been blown, an accident that often happens under the present conditions of evaporation. This rejected salt must be more like the natural deposit in composition than the salt as prepared for sale.

An analysis of the soluble part of the material was made by Mr. J. G. Rose, of the Analytical Laboratory:—

$NaCl$ (common salt)	73.80
$MgSO_4$ (Epsom salt)	16.98
$MgCl_2$	4.63
$CaSO_4$	2.16
KNO_3 (nitre)...	2.11

Fresh water, or rather very slightly brak water, is got from a well about 200 yards from the pan and nearer the old river bed, and good water for stock comes from a small spring on the north-east side of the pan.

5. *Nitre in Hay.*

This substance occurs in between the projecting layers of jasper on the krantzes in the Griqua Town beds. It is crystallised in such a way that the mass has a fibrous appearance, and the fibres are perpendicular to the enclosing layers of rock. The nitre is white or slightly stained, and the layers are of various thicknesses; those I saw did not exceed two inches in thickness, and they thin away inwards, for the spaces they occupy are due to weathering from the surface.

A few farmers make a little money each year by collecting the nitre, which is picked out with a knife or chisel; but, so far as I could ascertain, there is no body of nitre large enough to be worked on a commercial scale. Unsuccessful attempts have been made to wash the ground under the krantzes, and thus obtain the nitre disseminated through it.

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GEOLOGICAL SURVEY

OF

PORTIONS OF THE DIVISIONS OF VRYBURG AND MAFEKING.

BY

ALEX. L. DU TOIT.

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GEOLOGICAL SURVEY

OF

PORTIONS OF THE DIVISIONS OF VRYBURG AND MAFEKING.

By ALEX. L. Du TOIT.

I. Introductory.

The area surveyed consists of a strip of country averaging nearly forty miles in breadth, and extending along the Transvaal border from Dry Hart's Siding in the south to Ramathlabama Spruit in the north.

The Divisional maps of this part of the Cape Colony, which are the only ones available, are on the rather small scale of 2,000 Cape roods (4·7 English miles) to an inch; it was therefore impossible to draw in the geological boundaries with much detail.

1. *Natural Features.*—The country is flattish or slightly undulating, with low hills and ridges, and occasionally a few abrupt kopjes of no great altitude.

Around Vryburg and to the north the surface is remarkably flat, and rises gradually towards the Mafeking border, along which is situated the main watershed of this part of Bechuanaland. The height above sea-level of the watershed is greatest on the Transvaal border (4,600 feet), and this falls somewhat towards the west.

The southern portion of this area is drained by the Dry Harts River, a tributary of the Vaal. The river channel immediately to the south of Vryburg is deep and narrow, but at Brussels Siding it opens out into a broad and fertile valley.

North of the watershed are branches of the Molopo River, *e.g.*, the Mosita, Setlagoli, and Maretsani Rivers and the Ramathlabama Spruit, which carry off the rainfall into the Kalahari.

This portion of Bechuanaland is a gently rolling country, with a gradual fall towards the north-west; hills and kopjes are rare, and are formed invariably by hard rocks, such as quartz-porphyry, quartzite, or magnetic rocks.

At one time the country supported an extensive arboreal vegetation, but owing to the demand for timber at the diamond mines, and to the continual grass fires, almost the entire area within easy reach of the railway has been deforested.

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Some twenty miles or thereabouts from the railway the forest country is first found, and away to the north and north-west there is a monotonous stretch of well-wooded ground. The vegetation is chiefly composed of various acacias, such as the Kameel boom (*A. giraffae*); the Hakdoorn (*A. detinens*) is fortunately not abundant. Around Vryburg and towards the south the country is dotted with Vaalbosch (*Tarchonanthus camphoratus*). Various grasses are usually abundant.

Water is only met with in pans and rivers after falls of rain; for the soil is so light and sandy that the moisture is readily absorbed. The farmers have in consequence to obtain all their water from wells, boreholes, or dams. The best supply is obtained from the dolomite; the diabase often yields water in considerable quantity, but the granite is a rather uncertain source of supply.

2. *The Geological Formations.*—The only accounts of the geology of this interesting district are a paper by Mr. G. G. Holmes* on the area west of Vryburg, and brief references to the formations at Mafeking by Passarge, Hatch, Philippi, and others.

The rocks which build up this portion of the Cape Colony are all, with the exception of the Dwyka formation, older than the Cape system. Some of the formations are new, and have therefore been given local names; others have already been described from the Cape Colony or from the Transvaal.

In descending order, the rocks may be arranged as follows:—

Recent.	Superficial deposits:—alluvium, river-gravels, sand, and calcareous tufa.
Karroo System.	Dwyka series:—shales, and boulder-clay.
Transvaal System.	Campbell Rand series:—dolomites, limestones, and cherts.
	Black Reef series:—quartzites, with interbedded volcanic rocks.
Ventersdorp Series.	Diabase formation:—diabases, amygdaloids, breccias, and conglomerates.
	Botman's Poort sandstones and conglomerates.
	Zoetlief Beds:—quartzites, flagstones, and cherts; quartz-porphyry, and trachyte; quartzites, flagstones, and arkose.
	Kraaipan formation:—magnetic quartzites and slates; phyllites; sericite, chlorite, and calcareous schists.
	Granite and gneiss.
	Schists and other rocks included in the granite and gneiss.

* Trans. Geol. Soc. S.A., Vol. vii., p. 130, 1905.

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There are also a few intrusions, chiefly basic in character; some of these belong to the Karroo dolerites, while others are of much greater age.

II. Schists in the Granite.

At a number of localities the granite contains inclusions of material that must have been derived from older formations. These inclusions are of irregular shape, and range in size from fragments having an area of a few square inches to patches covering an acre or more in extent.

Some of these, *e.g.*, the sillimanite and cordierite rocks, probably represent highly metamorphosed sedimentary material, but the origin of the hornblende and associated schists is by no means clear.

1. *Sillimanite Rock.*—This occurs on the farm Oaklands, a little to the north of Mafeking, the outcrop being a single mass in the midst of red sand. About a quarter of a mile away, at the homestead, the granite is exposed in wells.

In the hand specimen the rock is light in colour, very much like clouded felspar, and with purplish mottlings, due to minute crystal aggregates of sphene. The material is massive, without any schistose structure, and its ability to withstand the blows of a hammer is nothing short of marvellous.

In thin section (1428) the great bulk of the rock is seen to be composed of bundles and aggregates of sillimanite needles (fibrolite); sometimes these are arranged close together in parallel positions, so as to resemble large crystals. Among these fibres occur larger and more well-defined prisms of the same mineral, which are usually elongated and indefinitely terminated. A few areas of clouded material showing crystallographic outlines may perhaps represent andalusite. Sphene, deep yellow-brown in colour, is present in great abundance, sometimes in well formed crystals. The specific gravity of the rock is 3.246.

2. *Cordierite Gneiss.*—On the farm Regen Vlakte, north of the Saltpan, a well has been sunk close to the homestead, through rather decomposed muscovite-granite (accompanied by aplite and pegmatite) into a hard greenish quartzitic-looking rock.

In the hand specimens these rocks are seen to owe their dark green colour to the abundance of dull green pseudomorphs (pinite) after cordierite. Muscovite has been developed enclosing the other minerals ophitically, and sometimes attains such a size that over an area of several square inches light can be reflected from different parts of the same crystal.

In thin sections (1406, 1407) the cordierite is seen to have some approach to crystallographic outlines, and is in large indidividuals enclosing quartz, leucoxene, and little zircons.

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The mineral has been entirely altered to a pale greenish aggregate, with very low polarisation colours, but the pleochroic halos still exist around a few of the inclusions. Quartz forms large patches; muscovite is abundant, and includes all the other minerals. Felspar is present in variable quantity, always clouded, and brown and opaque at the edges. Leucoxene is abundant, and there are a few small pink garnets, and numerous little zircons.

Some of the rock is light in colour (due to abundant felspar), with large green pinite pseudomorphs as much as one-third of an inch across; muscovite is then practically absent.

There are bands of dark hornstone in the formation, which are sharply defined from the surrounding rock.

No outcrops are seen in the neighbourhood, as the depth of soil is here considerable.

3. *The Hornblende and Associated Schists.*—These rocks, which vary exceedingly in character, have an extremely great resemblance to many of the sheared basic intrusions so commonly found in granitic areas; the presence, however, of veins of granitic material ramifying through the schists is sufficient to show that the latter are earlier than the granite. Basic rocks seem to be most common, but acid varieties are probably quite as abundant, though their resemblance to the gneiss is so great that they readily escape observation.

(a) Localities.—One of the best localities where these rocks may be studied is about 2¼ miles south of Maribogo Station, in several trenches along the railway. The granite is a foliated muscovite variety, medium-grained and passing into banded muscovite and biotite gneiss. The schists form irregular streaks and patches in the gneiss, and the foliation in the two formations generally has the same strike, a little north of east, and dip, to the south at angles of from 40° to 60°.

None of the inclusions can be traced continuously for more than a few yards, for the rock is penetrated by numerous veins of granite and aplite, both along and across the foliation planes. In many places the material of the schists is permeated with thin films of granitic rock, and there has been such an intermingling of material that it is difficult to discover the original limits of the inclusion.

Quartz veins traverse the gneiss and schists in various directions, and there are numerous little faults and slips in the rocks with their faces coated by films of mica.

The more acid schists are nearly always decomposed to a sandy material where exposed in the cuttings, but they are seen in the fresh condition in some knobs of granitic rock, and are traversed by veins of that material along and across the foliae.

The laminae of the schists are often greatly contorted, but the foliation planes in the gneiss surrounding the inclusions generally run evenly.

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At Setlagoli, on the right bank of the river, there are several most interesting exposures of these schists, some of which are contorted garnetiferous varieties. The strike of the foliation planes of the schists is sometimes coincident with those of the gneissic granite, but at other times it is almost at right angles to the latter.

Veins of granite, aplite, and quartz ramify through the schists, and in many places follow the contorted foliation planes.

For several miles down the Molopo River, just west of Mafeking, there are exposures of schists and granite, so interleaved as to form well-banded hornblendic gneiss, with foliation planes striking nearly due north. The composite nature of the material is everywhere made apparent by the lenticles of schist, cut by veins of granite and aplite.

At the junction of the Molopo with the Madibi Spruit there are fine outcrops of contorted schists, some of the layers being composed of large prisms of black hornblende.

A large area covered by similar rocks exists on the Ramathlabama Spruit, about two miles above its junction with the Molopo River.

These schists resist weathering to a greater degree than the enclosing granite, and their extensive development is indicated by the number of blocks found embedded in the red sandy soil of the district.

(*b*) *Petrographical Description.*—A thin section (1403) of an acid variety shows a large quantity of biotite in small flakes, mostly altered to chlorite. The ground mass consists of quartz, orthoclase, and plagioclase, the felspars being of rather large size. The structure is gneissose.

Of the basic schists there are many varieties, and quite commonly we can trace a regular change in the nature of the material from the centre of the inclusion to the contacts with the granite.

Thus, generally speaking, the cores are well-banded rather granulitic rocks, mostly garnetiferous, and containing hornblende, augite, and epidote. The rock passes into hornblende-augite-schist, biotite-hornblende-augite schist, and then into a talc-schist, with more or less unaltered ferro-magnesian mineral.

The borders of the inclusions were affected to a greater degree by the shearing movements that caused the foliation of the granite, and they were also acted upon to no small degree by the granitic magma. The interchange of material is sometimes shown by the production of quartz and orthoclase in the rim of the inclusion and by the development of biotite in the surrounding granite.

The following is a description of some of the rocks in thin section:—

No. 1397, from centre of an inclusion near Maribogo:—A well-banded granulitic rock, showing different layers character-

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ised by the predominance of different mineral constituents. Green hornblende sometimes showing approach to idiomorphic outlines and pale greenish augite with similar characters; the two are usually mutually interfering. Plagioclase felspars are abundant; in some parts of the slide they are clear and have rounded outlines, in other parts they form clouded aggregates. There is sphene and garnet, while epidote is present in large quantity, and has been formed after the above mentioned minerals. Zoisite has been produced last of all, and is moulded on the epidote, garnet, etc.

This grades into No. 1398, which is quite different. The hornblende occurs in parallel intergrowth with pale augite. The latter, but not the former, has little tubes of quartz ramifying through it, recalling a micrographic structure. The spaces between the crystals are partly filled by epidote, with similar tubular structures. Felspar is present, but is rather clouded, and contains calcite.

No. 1399 is a typical hornblende schist. The hornblende is abundant in deep green prisms, which usually include quartz in the form of blebs. There is a little clear plagioclase felspar.

This rock passes into a biotite-hornblende-augite schist, and that again into a highly sheared talcose-schist.

The section (1400) shows plates and fibres of talc and serpentine, the latter having probably been formed from biotite (through chlorite). The rock contains calcite, magnetite, and haematite. This talcose-schist occurs close to the junction with the granite.

At Setlagoli the rocks are somewhat similar.

No. 1412, from the core of a large inclusion, shows large pink garnets in irregular grains and aggregates enclosing apatite and sphene. Pale green pyroxene is usually bordered by green hornblende, and may show a diallagic structure. The hornblende commonly contains little tubes of quartz, which expand in places to form blebs; this reverses the conditions seen in No. 1398. Sphene and apatite are also included. Epidote is abundant in large, nearly colourless plates, ramified by veins and tubes of quartz. Quartz is present also in small, irregular areas, and so is calcite. Sphene is present in unusual quantity, in granules which are crowded together to form aggregates; apatite is also very abundant. Felspar was the last mineral to form, and surrounds all the other constituents. It is very much clouded, but still shows repeated twinning.

No. 1411 is a well foliated rock, containing very large prisms of pale yellowish-green augite, with their longer axes arranged in the same direction. Felspar, slightly clouded, fills in spaces between, and sometimes encroaches upon, the augites; it sometimes shows repeated twinnings. Sphene is abundant as inclusions in both these constituents.

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The rock passes into a dark talcose rock, with somewhat schistose structure, and containing a good deal of unaltered augite.

III. The Granite and Gneiss.

Although granitic rocks cover the greater portion of the Mafeking Division, there are but few places where any considerable natural exposures can be seen.

The only places where the rock can be well examined are at Maribogo and down the river to Setlagoli, on the Mosita Native Reserve, at Kraaipan, and along the upper portion of the Maretsani River; elsewhere there are isolated outcrops, and its presence underground is inferred from the character of the soil or from the material brought up during well-sinking operations.

(1) *Petrographical Description.*—The granite is usually a white, grey, or pinkish gneissic variety, containing muscovite, and nearly always medium grained and never porphyritic in character.

In a few places the mica is biotite, and muscovite may or may not be absent.

In most of the granites there seems to be a certain amount of oligoclase felspar, in addition to orthoclase and microcline. In a specimen (1395) from Maribogo, there is well shown the production of lamellar twinning in orthoclase felspars in certain parts of the crystals that have been subjected to strain.

The microcline is the last constituent to crystallise, and surrounds and penetrates between the earlier formed minerals. The microcline resists alteration both chemically and physically to a greater degree than the orthoclase and oligoclase.

Granites, other than micaceous varieties, are also represented.

From Zwart Laagte, near Setlagoli, a sample (1415) taken from a borehole proved to be a hornblende-granite.

At Oaklands, north of Mafeking, a well has penetrated an augite-granite. The thin section (1427) shows a granulitic aggregate of quartz, orthoclase, and oligoclase, in which are set irregular grains of feebly pleochroic greenish augite. Another specimen from this well has a similar mineral composition, but the greater bulk of the rock consists of pyroxene.

At the farm West End, in the lower portion of the Maretsani River, there are banded rocks of nearly similar composition.

The thin sections (1413, 1414) show granulitic gneisses, with pale green pyroxene and epidote; the latter may be an original constituent. In the first section apatite is most abundant; in the second sphene forms numerous crystals, with rather well-developed faces.

(2) *Pegmatites and Veins.*—Pegmatite veins are very abundant, but seldom have a width of more than a few inches. They

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ramify in all directions through the granite, but a little north-east of Kraaipan the majority of the pegmatites trend in a northerly and southerly direction. Graphic intergrowths of quartz and microcline felspar are not very common, but there are good examples at Maretsani Siding. Muscovite predominates over biotite as a constituent. About half a mile south-east of Kraaipan Siding a pegmatite contains a certain amount of fluor-spar and pyrites.

Aplite veins are sometimes common, but usually only occur penetrating the patches of schist which have been included by the granites. They are never more than about a foot in width. Under the microscope the rock proves to have a granulitic structure.

Granite Veins.—I have only noticed one granite vein, about twelve inches in width, at a point on the railway two and a half miles south of Maribogo Station. It cuts nearly vertically through both the granite and the included schists.

Quartz Veins.—These are very abundant, from small threads up to reefs as much as 40 feet broad. They consist of milky-white quartz, sometimes rather chalcedonic, and in places contain small amounts of tourmaline or iron pyrites, but they never appear to carry any appreciable amount of gold. They have no fixed direction of strike.

Pyrophyllite Rock.—An occurrence of this material was noticed along the railway two and a quarter miles south of Maribogo Station. It forms a vein about 4 feet wide cutting nearly vertically through the granite. Some quartz veins in the latter are truncated by this material. The rock is tough, though soft, and is composed of numerous small pearly plates of pyrophyllite. It is stained by iron compounds, and contains perfect little octahedra of magnetite. The material resembles a talc-rock to a great degree, but the absence of magnesia and the presence of alumina were proved chemically.

As to the origin of the material it is impossible to be certain. Pyrophyllite is produced by the alteration of potash felspars, and is one of the intermediate stages during the formation of kaolin. Possibly it may have been formed from an acid intrusive rock or from material in a belt of crush and weathering in the granite.

(3) *Foliation.*—With the exception of those in the Mosita area, all the granites show foliation to a greater or lesser degree, so that in many places the term gneiss is more applicable. Around Maribogo and Setlagoli these foliation planes have a very constant strike a few degrees north of east; on the Maretsani River at the Railway Siding, and again further down at West End the strike is about north and south. The dip of the foliation planes is variable, and in some places they are slightly contorted.

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A certain amount of the foliation appears to have been produced by the flow of the molten material during the period of injection. This is shown in several ways. Firstly, in quite a number of places the minerals in the pegmatite veins are quite unaffected and undistorted. Secondly, and this is well shown at Setlagoli, the foliation planes in the granite do not pass through the included schists. The latter have their own foliation planes, which are contorted, and strike north and south, *i.e.*, almost at right angles to that of the granite.

Lenticular patches of schist very often conform in dip and strike with the direction of foliation of the enclosing granite, in which case the two rocks have parallel foliation planes, but this is apparently largely due to the twisting round in the molten mass of these patches of rock, so that their larger surfaces were set parallel to the direction of flowing.

It is equally true that later movements have produced shear structures in the granite, and at Maretsani Siding the mica plates in the pegmatite veins have been bent, while some of the crystals of felspars have been much distorted. The shearing is most intense in the proximity of the thrust-planes bounding some of the belts of the Kraaipan formation. A specimen from the farm Holland shows the following characters in thin section (1430) under the microscope:—

The felspars are drawn out in the direction of shearing, and are faulted and broken, but usually resist the stresses far better than the quartz; the ground-mass consists of a medley of fragments of quartz and felspar, and the planes of shearing are marked by films of muscovite.

Another example (1405) from the contact with the magnetic rocks at Gemsbok Pan shows granulitised quartz, and sheared and distorted muscovite plates, while the felspars have been replaced by aggregates of quartz and some micaceous mineral.

A coarse-grained granite from Mosita (1417), which is almost devoid of mica, shows lines of fracture and crush which have been lined with chalcedonic and filled in with opaline silica.

IV. The Kraaipan Formation.

There is in the Mafeking Division a considerable development of schists and magnetic quartzites and slates, which are closely paralleled by certain rocks in Bloemhof (Abelskop), Pietersburg, Barberton, Swaziland, and elsewhere.

These schists and ferruginous rocks have been grouped together by different observers under the names of Barberton beds, Swazi Schists, Namaqualand Schists, and "Primary-formation."

As these terms are not very well defined, and in some cases misleading, it has been considered justifiable to give the Bechuanaland rocks a purely local name, especially as there is nothing

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as yet to indicate a similar age for these various scattered occurrences of rocks, except their lithological resemblances.

Distribution.—The formation must at some very early period in geological history have covered a great area in this district; earth-movements and denudation, however, have removed the greater portion, and left but little except three narrow areas, which form rather discontinuous and more or less parallel belts.

The *Eastern belt* is that at Madibi, having a general north and south trend.

The *Central belt* occurs at Kraaipan, and extends southwards into the Khunwana Reserve (Transvaal), while in the opposite direction it stretches across the Maretsani River, and then forms a series of detached ridges, which are very prominent at Pitsani.

The *Western belt* is well developed at Mosita, but has not been followed northward beyond Blik Plaats. Southwards there are ridges at Wonder Klip, and the rocks project through a cover of diabase at the Saltpan and at Monjana Mabedi.

Tectonic Geology.—Deposited originally unconformably upon the granite, the beds have been intensely folded and sheared, so that in but few places are these two formations found preserving their original relations.

Faulting and thrusting have taken place on an extensive scale, and in a great number of outcrops the boundaries on one or both sides consist of thrust-planes.

The formation being of considerable thickness, it is evident that the lithological differences noticed between different outcrops may be due, partly to the fact that beds caught between the thrusts have been derived from different geological horizons, and partly to the nature and degree of the metamorphism which these beds have undergone.

There appear as well to be certain lithological differences, which can only be explained by an alteration in the character and nature of the original sediments along or across their strike.

General Lithological Characters.—For general purposes the rocks of the Kraaipan formation may be arranged in four classes:—

(*a*) *Ferruginous rocks.* magnetite-quartz rocks (quartzites and slates), magnetite-actinolite rocks, and ochreous quartzites and slates.

(*b*) *Cherty rocks*: massive and banded cherts, ferruginous cherts, and jaspilites.

(*c*) *Schistose and slaty rocks*: sericite, actinolite, and pyrophyllite schists.

(*d*) *Calcareous rocks*: limestone, ferruginous dolomite, and calcareous schists—these are poorly developed in this area.

The rocks are all highly veined with quartz both along and across the bedding planes, and, as will be seen later, these reefs have apparently been produced at different geological periods.

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Stratigraphical Divisions.—The formation may be divided up into three portions:—

(i) a lower group, characterised by a very massive bed of magnetic quartzite and alternations of thinner beds of that rock and phyllite, etc.;

(ii) a middle group, composed essentially of cherty rocks, with but an occasional slaty or quartzitic bed; and

(iii) an upper group, in which magnetic slates, cherty rocks, phyllites, and schists alternate rapidly in beds of no considerable thickness.

Of the limestones, some belong to the lowest division, but the exact horizons of the others are not known.

The formation, or rather that portion of it represented in the Mafeking Division, must be at least 10,000 feet in thickness, even after making due allowances for the repetition of some of the beds by folding.

Owing to the recent discovery of gold at several places, notably at Madibi, the Kraaipan formation acquires considerable interest, hence the following detailed description of the various belts of rock.

Description of Occurrences.

I. *The Central Belt:—Kraaipan-Pitsani.*

It will be most convenient to commence with the description of the outcrops at Kraaipan, for there the formation is least disturbed, and attains its maximum thickness, while the unconformable relation of its base to the granite is well shown (see fig. 1); (the two cross-sections are taken along lines four miles apart).

At Kraaipan Siding the belt is not much more than half a mile across, but when followed northwards this increases rapidly, and on Wodehouse Kraal it attains a width of three miles. The lowest bed of magnetic quartzites forms a long line of rugged black kopjes, broken at two points where its outcrop has been shifted westwards by transverse faults for a considerable distance. The chert zone forms a low, well-wooded, and more regular ridge, while the strata forming the upper zone are more or less concealed by sand.

The actual base of the formation is exposed along the railway west of Kraaipan; elsewhere the junction with the granite is hidden by sand. The massive muscovite-granite contains at this point several bands rich in biotite, which cross it, and which are now sheared into a biotite-gneiss.

Upon the granite and gneiss rests a silvery mica-schist, with foliation planes dipping eastwards at an angle of about 70 degrees. This passes into greenish sericitic schist and soft phyllite, which is followed by the lowest magnetic quartzite, with a dip of from 45 to 50 degrees. The thickness of these

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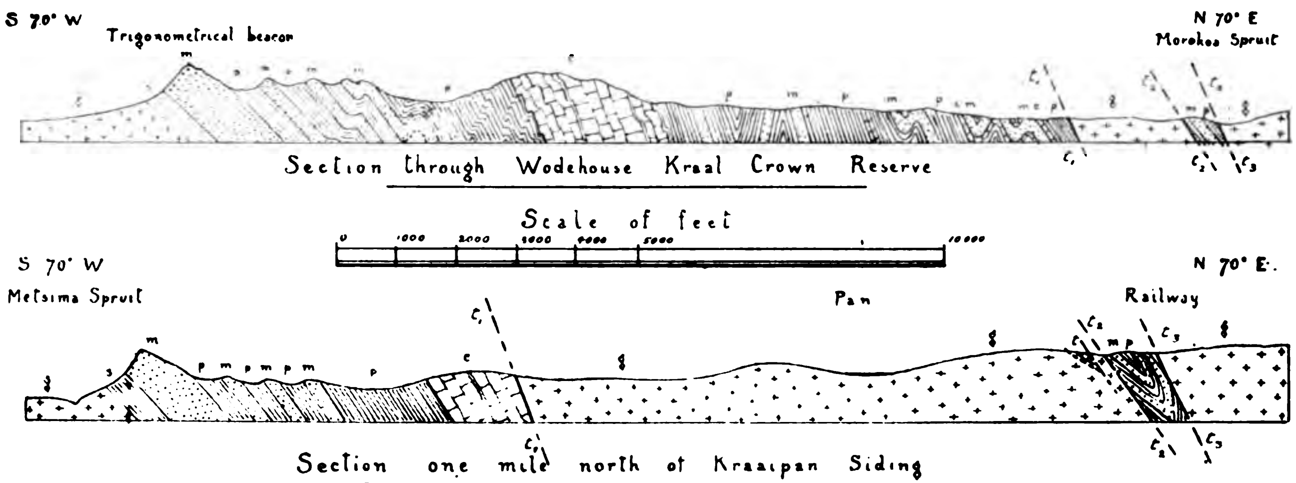

Fig 1 γ . granite ; s . sericite schists , m . magnetic quartzites and slates ; p . phyllites etc ; c . cherty rocks
t . t . thrust-planes

basement schists cannot be more than about 50 feet, and in all probability the planes of foliation cross those of bedding. This magnetic quartzite, about 60 feet or more in thickness, is followed in turn by alternations of magnetic slates and greenish phyllites and sericite schists, the softer beds being but seldom exposed. Some prospecting shafts have proved this formation, and a well along the railway just west of the siding is sunk in a hard chlorite slate, and gives a good supply of water.

North of Kraaipan Siding, the chert zone first appears, and is well exposed on Wodehouse Kraal, where prospecting shafts have been sunk in it. These cherty rocks vary in colour from white to blue-black, and are usually well banded, and pass on the one hand into cherty rocks with magnetite and on the other into massive brown cherts with banding but feebly developed. Thin layers of greenish and ferruginous phyllite are also present.

At a point about a mile north-north-east of Kraaipan Siding there are thin beds of actinolite-magnetite rocks, like those to be described later from Maribogo.

The eastern contact with the granite is nowhere seen, but the position of a dislocation can be fixed fairly closely by means of scattered outcrops. Towards the north the thrust-plane gradually cuts out the higher beds, and on Lenton the whole of the formation has been overlapped by the granite.

At the boundary between Lenton and Spanover there are thin inconstant red bands in among the black quartzites, the red colour being due to haematite.

East of the main outcrop there are evidently two nearly parallel thrust-planes, by which portions of this formation have become wedged in the granite.

The patch two and a quarter miles north-east of Kraaipan is of interest, since a small opening along the railway show a fault separating magnetic slates from a foliated granite. A number of prospecting trenches exist here, and show the character of the beds very clearly, besides revealing their rapid change both of dip and strike.

North of Wodehouse Kraal the distance between the thrust-planes increases to about a mile, the rocks between them including the chert zone and a certain thickness of the beds above and below it. This belt crosses the Maretsani River, and along the banks there are good exposures even of the bands of soft green phyllite. A small patch of breccia containing blocks of crushed granite, magnetite rock, etc., marks the position of the eastern thrust.

On the north bank the formation forms Methuen's Kop, the feature being due to the hard banded cherts, which here contain thin layers of red jasper. The chert becomes more ferruginous above and below.

The belt of rock terminates abruptly at Methuen's Kop; to the north are wide sandy flats, supporting a very scanty vege-

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tation, and no rock is exposed. The termination may possibly be due to the rapid approach and intersection of the two thrust-planes.

Midway across these flats, between the Maretsani and the Molopo Rivers, there rise out of the red sand two prominent hills, known as the Mosadiapitsi Kopjes.

On the eastern hill are massive magnetic quartzites, with a strike a little north of east, which pass abruptly into a hard brown banded limonitic rock, cherty in places. This brown rock probably overlies the other, but whatever the order of succession, there is a considerable amount of inversion of the strata as these are followed along the ridge.

The western hill, on which the beacon stands, consists of extremely folded magnetic quartzites, the strike and pitch of the folds altering rapidly even within very short distances. The axis of each fold is marked by very great contortion, these minor wrinklings being of an isoclinal character.

Immediately west of Pitsani is another great ridge, which is continued north of the Molopo into the Bechuanaland Protectorate.

The river runs in a narrow gorge about half a mile in length, and in places about 200 feet deep, so that a splendid natural section through the formation is thus afforded. The rocks are remarkably massive in character. The magnetic quartzites form thick layers, which are broken up into great cubes by means of joints; the slates are ochreous, and in but thin bands. The dips are at angles of from 45° to 75° towards the south-east, and the strata are traversed by quartz veins, often of no small width. Further down the river are flats, with sand and pebbles, and then sheared mottled ferruginous and micaceous quartzites and green sericite schists. To the south is a flat of red sand, with small outcrops of rock here and there.

Along the Molopo River, between Pitsani and Mafeking, are several strips of this formation, forming a link between the rocks of the central and those of the eastern belt.

About three miles east of Pitsani, but on the northern bank of the Molopo, is a narrow belt of creamy crystalline limestone with an easterly strike. The rock is cherty and ochreous in places, and shows signs of shearing; it contains a certain amount of magnesium carbonate. Since it passes into ferruginous slates it must be considered to belong to the Kraaipan formation.

On the Piring Spruit, about a quarter of a mile above its junction with the Molopo, is a narrow belt of ferruginous and cherty quartzites, not more than a hundred yards wide, and striking a little south of east. It contains numerous layers of white quartzite a few inches in thickness, and is bounded on either side by a basic igneous rock.

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Close to Jan Massibi's stad, and again a few miles west of Sanie's stad, the Molopo is crossed by narrow belts of magnetic-quartzite, having a north-easterly trend.

As the granite (with included schists) is in each case seen within a few yards of the ferruginous rock, it is very probable that these are infolds of the lowest magnetic quartzite, with the basal sericite schists not developed.

II. *The Eastern Belt:—Madibi.*

On account of the auriferous character of some of the rocks at Madibi, this is the most important outcrop of the formation.

The strata are very badly exposed, and in several places there are wide stretches of either sand, black earth, or river-gravels; our knowledge of the rocks forming this belt would therefore be very small were it not for the numerous trenches and other artificial openings.

On the farm Weltevreden, along the Maretsani River, is a small opening, showing a coarsely crystalline magnetic quartzite in contact with gneissic granite. The junction with the granite is very sharp, and the rock shows no signs of contact metamorphism. The bed forms a little syncline, pitching south at a very high angle.

On the south side of the Maretsani River, in the angle between it and the Transvaal border, are openings in an inlier of granite and the Kraaipan beds, surrounded by diabase. The trenches show sharp junctions between the coarse magnetic quartzites and the granite, and the beds are probably infolded in the latter, for neither the granite itself nor the pegmatites which traverse it send tongues or veins into these quartzites and slates.

It is on the boundary between Kirby and Stoneham that the Madibi belt proper commences; south of this there is nothing but the later diabase. At the beacon K. 4 there are several openings, two of which expose the junction with the granite. In one of these the contact is apparently a fault-face, but in the other the strata are bent into an arch over the granite, and the axis of the fold dips away at a moderate angle to the north.

There is a layer of sericite-schist a few feet in thickness between the granite and a rather unusual type of iron-ore rock.

The latter consists of crystalline quartz slightly bluish in colour, and much resembling vein quartz, but with the bedding planes marked out by rows of haematite crystals.

Apparently the original sediment was less ferruginous here and more siliceous than usual, for the rock passes upward into a magnetic-quartzite.

On Eastwood openings show the dips to be rather variable, often either to the north or south. These dips, taken into conjunction with the evidence from the exposures on Kirby and

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Weltevreden, show that in this part of the district the folds which form the belt, and which trend north and south, are crossed by transverse flexures, giving rise to detached basins in the granite.

However, from Eastwood onwards the belt is continuous, and the gneissic granite is exposed on one side or the other in wells. Apparently the folds must pitch in a northerly direction, and from Holland onwards the boundary on each side is most probably a thrust-plane. On the latter farm a finely sheared granite appears in an opening on the west side of the ridge, while a little distance further north there is a shaft in a highly sheared ferruginous dolomite associated with magnetic slates.

On the east side of the ridge, at the northern homestead, there is an excavation in sheared granitic gneiss, while 60 yards to the west is a deep shaft in green mica schist and schistose green micaceous quartzite.

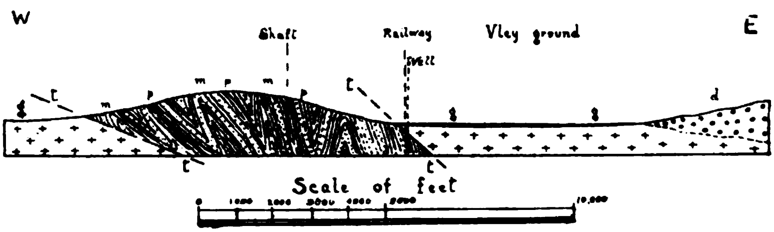

FIG. 2.—Section through Madibi. *g*, granite ; *m*, magnetic quartzites and slates ; *p*, phyllites, etc. ; *d*, diabase and amygdaloid ; *t*, *t*, thrust-planes.

Along the east side of the ridge from Holland to beyond Madibi there are several openings, showing gneisses ranging from muscovite to biotite varieties. In the well along the railway at a point a quarter of a mile south of the siding, the gneiss is apparently underlain by a talcose-phyllite. Probably this well has been sunk through the eastern thrust-plane (fig. 2).

The numerous trenches which have been excavated all along this ridge, usually in a direction across the strike, show the nature of the formation and the structure of the belt. As indicated in the accompanying section (fig. 2), the beds are arranged with some approach to a fan-structure. In many of the trenches either the crest or trough of a sharp fold is visible, with the two limbs pressed closely together. The folding seems to be fairly regular, and to have considerable amplitude.

The rocks are usually thinly-bedded, and there are hardly any bands of magnetic quartzite more than a few feet across. The formation consists of layers of evenly bedded magnetic and haematitic quartzites and slates, with greater thicknesses of phyllites, and sericite, chlorite, and calcareous schists.

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Usually there are rapid alternations of harder and softer rocks, and it is very difficult to follow the same bed for any distance with certainty along the strike, even where the cuttings are quite close together.

There are several prospecting shafts close to the railway, but the description of the auriferous material exposed by them will be given later.

North of Madibi the formation can be followed for several miles, for the rocks are occasionally shown in trenches or shafts. The belt then passes below vley ground (black earth and pebbles), but there are openings again at a point about a mile and a half south of the beacon K·14.

On the ridge on which K 14 stands, the formation is not exposed, owing to a thick capping of ancient river-gravels, but the beds probably continue below ground, and are exposed in the valley of the Molopo River, in a trench a little below the spot known as Willow Dam, beside the road to Pitsani.

Here there is a great development of green phyllite and micaceous and quartzitic schists, with only a very small amount of ferruginous rock. The belt is traversed by numerous quartz veins, but none of these have proved to be auriferous.

The width of the outcrop is narrow; the strike is a little north of west and the dip easterly.

On the west side of the belt there is a zone of highly crushed and silicified gneissic rock, about 250 yards in width. The rock has been so shattered and crushed that in places only fragments of the felspar can still be recognised; there is, however, a gradual transition westwards into a muscovite-gneiss. In much of the altered material lenticles of rock occur which have escaped crushing to a greater or less degree, and in which the gneissic structure is yet visible.

The crushed material appears to have been firmly cemented with secondary silica, and its mode of occurrence suggests that it marks the position of the western thrust-plane.

Between the Molopo and the Ramathlabama Spruit little knobs of magnetic quartzites appear now and then, through the thick mantle of red sand.

III. *The Western Belt:—Monjana Mabedi—Mosita.*

In the Vryburg Division this formation has been overlapped by the Diabase, and the outcrops at Monjana Mabedi and the Saltpan are inliers amid the younger rock.

At the former locality the outcrops form two dome-shaped hills, almost united at their bases, and which are visible from a great distance.

The rock exposed is almost entirely a massive brown, grey, purple, or black chert, highly brecciated and veined with chalcedony and quartz, and never showing any traces of bedding.

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The northern hill, Spits Kop, which rises to a height of about eighty feet, is formed entirely of these rocks, but in the southern hill, on its eastern side, is a narrow belt of fine-grained magnetic slate, with high dips, often contorted, striking a little west of north. On the west side of the hill there are brownish sheared ochreous rocks, more or less quartzose and cherty, containing some carbonate.

At the Saltpan the long ridge west of the pan is composed of cherty rocks, more ferruginous and banded than those on Spits Kop. Towards its south-eastern extremity, immediately behind the Police Camp, there is a great amount of breccia, in which the abundant cementing material is red-brown haematite.

On Wonder Klip there is a wide ridge, composed chiefly of cherty rocks, but magnetic quartzites are also represented, especially on the eastern side, and are useful for indicating the varying dip. On the west side a well at the homestead has been sunk in a gneissic muscovite-granite.

From the main mass at Wonder Klip, a narrow belt, bounded apparently on both sides by thrusts, extends northwards across Papies Vlakte, and then acquires a north-westerly strike; from a distance it resembles one of the dark dolerite ridges of the Karroo.

A little north-west of the homestead on Papies Vlakte, an opening shows beneath the magnetic quartzite a coarse-grained and highly sheared variety of granite.

On Gemsbok Pan the formation makes a high ridge, towards the summit of which, and on the west side, there are numerous trenches and shafts.

The sections show that the formation is very much disturbed. The muscovite granite is highly sheared, and traversed by small quartz veins and stringers. There are alternations of crushed granite, vein quartz, brecciated vein quartz, chert, and magnetic quartzites; in some places the granite has been thrust over the latter, in others it underlies them.

The rocks are much brecciated and silicified, and quartz reefs occur commonly along the fault-planes separating the two formations.

Most of the trenches were excavated in order to lay bare a wide quartz reef, which, I am informed, gave in places fairly high assays.

At the summit of the hill the rocks are well exposed, and the quartzites contain much haematite, as well as magnetite. These massive beds, which are repeatedly folded and contorted, correspond to those seen at the base of the formation at Kraaipan.

While the outcrop extends only a couple of miles north-westwards, the parallel belt, a mile to the east, passes right through the Mosita Native Reserve.

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It is probable that on Groot Gewaggd, where this belt commences, the formation rests normally upon the granite, but northwards the junctions on both east and west sides seem to be faults.

On Mosita the belt consists principally of white grey or black cherts, well banded, and containing thin layers of jasper and beds of magnetic and haematitic quartzites and slates.

The strata, which usually dip vertically and have a strike which does not quite coincide with the direction of the belt, are somewhat folded and traversed by numerous transverse faults.

These fractures, which have usually a throw of not more than a few inches, are quite abundant and arranged close together in step-like fashion, and are often accompanied by minute threads of vein quartz.

On the farm Parnell the formation is absent for some distance, being cut out apparently by the upper thrust plane.

On Moshesh the beds re-appear, and the outcrop rapidly widens, to form a band over a mile wide, and through which the Mosita River has cut its channel diagonally.

The lower beds consist of the usual massive magnetic rocks, which are here rather cherty, and contain thin bands and patches of bright red jasper. On Blik Plaats the beacon on the left bank of the river stands on a wide ridge of these rocks, the great breadth of which is probably due to repeated folding.

The low hills east of the river are formed of massive white or buff cherts and banded translucent, white, grey, black, and jaspery varieties. A most conspicuous rock is a beautifully banded red jasper, often in thick beds and of wonderful brilliancy. It contains ferruginous and translucent layers, and is traversed by veins of quartz.

It is interesting to find in this formation such a development of jasper, hand specimens of which are identical with rocks in the Griqua Town series of Hay, although the two formations differ so greatly in age.

Beyond Blik Plaats the belt was not followed, but it is probable that it extends northwards for many miles further.

IV. *Occurrences between the Central and Western Belts.*

At Maribogo the magnetic rocks form a ridge, U-shaped in plan, opening to the north-west, having its north-eastern side practically coinciding with the Transvaal border.

On this side the strata dip north-eastwards at angles of from 40 to 65 degrees, and possibly the beds may represent the Khunwana extremity of the Kraaipan belt, shifted westwards by means of a transverse fault.

In the angle of the border fence the dip is easterly, the outcrop curves round, and the rocks form a series of black ridges just within the Transvaal.

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The flats are covered with red sandy soil, but there is nothing to negative the supposition that the junction with the granite is an unconformable one.

The massive rocks forming this ridge east of Maribogo correspond to the basal bed so well exposed at Kraaipan, but here, however, actinolite has replaced quartz, sometimes to such an extent as to convert the magnetic quartzite into a magnetite-actinolite rock. These rocks are well banded, and sometimes require careful examination before the ferro-magnesian mineral becomes apparent, as there is no change either in the mode of weathering or in colour.

In some layers the actinolite is so abundant in large crystals over an inch across as to give one the impression that the material is of igneous origin.

These magnetite-actinolite rocks include layers of magnetic quartzite, while further south and south-east, along the strike, the actinolite diminishes rapidly in quantity as a constituent, so that in the south-western ridge the magnetic rocks are essentially quartzitic. These magnetic quartzites are here succeeded by flaggy ferruginous beds, brownish yellow to purplish in colour, sometimes of the nature of a sandstone, and at other times rather cherty. The beds are usually rather ochreous, and contain only a very minute quantity of magnetite. They recall similar rocks at Mosadiapitsi, and probably represent altered phyllites. Cavities now filled with ochre may perhaps at one time have contained crystals of iron carbonate.

In the south-western ridge the rocks all dip to the south-west; nevertheless the granite appears in that direction.

Further, again, at the base of one of the two little hills at the northern end of the ridge there are two wells in horizontally-foliated gneissic granite, towards which the sedimentary rocks are dipping.

No normal system of faulting can explain the nature of the contacts, and it is reasonable to suppose that the magnetic rocks composing the south-western ridge and the two hills to the north form merely cappings on the granite. In several places on the ridges there are overfolds, as well as rapid variations in strike.

The most probable explanation of the structure is that a thrust plane bounding the east side of the north-eastern ridge curves downwards over the latter, and then passing horizontally beneath the cappings of magnetic rocks in the south-western ridges, separates these sediments from the underlying granite. Several smaller discordances can be accounted for by means of the minor thrusts which would accompany this major thrust-plane.

The displacement of the beds from their original position is probably not more than about half a mile in a westerly direction.

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North of Maribogo the same structure seems to occur, but the strata in this case must have been displaced a distance of several miles along the corresponding thrust-plane.

At Setlagoli massive magnetic rocks form a little hill on the left bank of the river. The dips are at high angles to the north and north-east, yet the formation is merely a surface cap, for wells and openings both on the south, south-east, and north show gneissic granite and schists included in the latter.

In the bed of the river, on the north-east side of the hill, there is an exposed surface, about 30 yards in diameter, of granite and gneiss breccia. The rock is intensely hard, and contains fragments of granites, various granitic gneisses, pegmatites, and schists (such as commonly occur in the granite), set in a matrix of mashed up granitic material. The fragments are usually somewhat rounded, and are often over a yard in diameter; whenever they are flattish, there is a tendency for the slabs to be arranged with their flat surfaces nearly horizontal.

Further up the river, and also in the higher ground, the normal granitic gneiss is met with, but about 600 yards downstream, and again about 300 yards further down, horizontal surfaces of similar breccia are well exposed.

I think that this breccia marks the position of the major thrust-plane, upon which the Setlagoli outlier rests; the outcrop seems to pass northwards down the valley for a few miles, for on Latham we find a similar but elongated outlier of magnetic quartzites, trending north and south.

The dips of the strata are as a rule eastward, but in places there is much contortion. Between several layers of magnetic quartzite, and sharply separated from them, there are outcrops of a rock composed almost entirely of pyrophyllite. The exposures are not good enough to see their exact relations, but as the pyrophyllite rock can be traced for over three-quarters of a mile, it possibly represents an original bed in the Kraaipan formation.

On the east side of the outlier the granite, accompanied by aplite and pegmatite, has been thrust over the magnetic quartzites, and now overlies them, the rock being highly crushed and powdered at the contact.

South-east of Doornbult Siding, and almost on the Transvaal border, there rises out of flat ground made of diabase a low ridge, about a mile in length, known as Leeuw Kop.

The magnetic quartzites forming the hill are sometimes cherty, in places recalling characters more prominent in the western than in the central belt.

The strata are folded into a series of small domes and basins, usually not more than one or two hundred yards across, which are finely exhibited at the highest point of the ridge. This structure must have been produced by the crossing of two sets of flexures. The beds are frequently brecciated to a considerable degree.

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About a mile and a half north of this hill there are similar outcrops of magnetic rocks, and a prospecting shaft shows greenish sericitic schist and schistose quartzite apparently underlying them.

There are numerous other occurrences of this formation, but of no great size; the most westerly point where these rocks were noticed is on Zoeteinval, below the quartzites of the Black Reef series.

Folding, Faulting, etc.

Whatever the nature of the magnetic-rocks originally, it is evident that the material contained layers of varying composition, which, as the result of metamorphism, caused the formation of alternating quartzitic and ferruginous bands.

The material was laid down unconformably upon the granite, and then subjected to considerable pressure from some northerly or southerly direction.

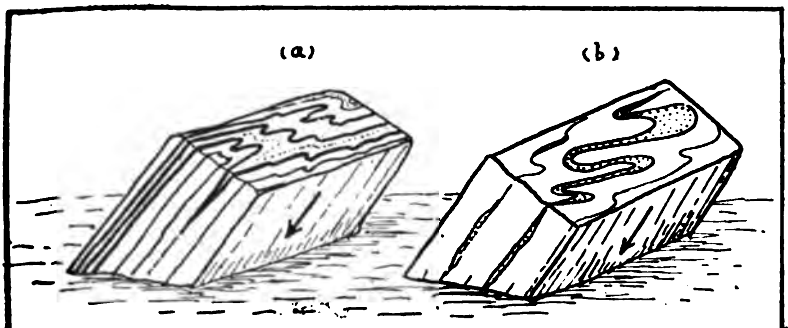

FIG. 3.—Diagrams to indicate the character of the contortions (*a*) of the bedding planes (*b*) of the earlier quartz veins. The arrow shows the direction of dip of the later planes of shearing.

Quartz veins were produced at an early stage, chiefly as thin lenticular layers between the bedding planes, but sometimes crossing them obliquely.

By reason of this pressure, small corrugations were produced, and both the laminae and quartz veins were contorted (fig. 3). In the central belt the strike of these contortions is approximately east and west; the same is the case at Maribogo, but at Leeuw Kop the direction is almost south-east.

These little folds are very often of an isoclinal nature, and their small amplitude and immense number indicate that they were formed while the strata were yet deeply buried.

The slates and quartzites are often traversed by small faults and crushes, while the quartz reefs have been granulitized, and now resemble to a great degree fine-grained quartzites.

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It is interesting to note that the same phenomena have been described from Abelskop,* in the Transvaal.

In connection with these east and west corrugations, it is worth noting that the south end of the Madibi belt shows folds with a similar strike, but with a very much larger amplitude; while on Wodehouse Kraal there are east and west faults, which seem to be older than the eastern thrust-plane.

At a later period the area was compressed from east to west, the strata highly folded, sheared, and cut up by thrust-faults through which portions of the formation were thrust over one another and much displaced; fissures were produced, which were filled by quartz veins.

The earlier wrinklings were to some extent modified by the new pressure, but the effect is seen mostly in the pressing together of the limbs of these minor folds into more or less parallel positions, over which shearing then took place.

The shearing action is shown by the striations which run in the direction of the dip, and by the distortion of the crystals of magnetite. The smaller crystals are unaffected, but the larger individuals have given way along partings parallel to the octahedral faces, and have therefore acquired a laminated structure.

There are seldom any puckerings visible on the faces of these new shear-planes, but the edge of each outcropping bed of rock shows the original contortions (*a*, fig. 3). These planes of shear are only developed in places where the original bedding-planes run parallel and close together for some distance.

For example, in (*a*), fig. 3, the block which is bounded by two such planes will not split directly through the middle, but will fracture with greater facility along the contorted bedding planes.

Thus the apparent bed-planes are in reality surfaces of shearing, but are nevertheless good indicators of the actual dip of the rocks, for their direction coincides with the general direction of the closely folded laminae; nowhere do we find colour bandings and other similar secondary structures crossing the bedding planes.

All the hard beds are mor or less traversed by joints parallel to the dip, and the more massive quartzites and hornblendic rocks are divided up into great rectangular blocks.

In the case of the softer rocks, it is probable that the original structures have to a considerable degree been obliterated, yet where the slates alternate with siliceous layers, the superinduced cleavages correspond very closely with the actual bedding.

* Jorissen, Trans. Geol. S.A., vol. VII., p. 152, 1905; Heneage & Holford, "Notes on the Occurrence of Gold in Primary Formations." Proc. S.A. Assoc. Engineers, 1905.

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Later movements are indicated by belts of more or less brecciated rock, often many yards in width, the angular masses of magnetic quartzite and slate being cemented by brownish chert, chalcedony, or white quartz.

The position of these breccias is commonly independent of the flexures in the strata; they occur quite as frequently in the midst of evenly bedded rocks; the date of their formation has probably to be referred to a comparatively late period, when the strata were but slightly buried and the rocks were too brittle to flow.

The Kraaipan formation must have been enormously denuded prior to the outpourings of the overlying diabase, but the presence east of Kraaipan of quartz reefs traversing this younger formation shows that many of the veins which cut the magnetic rocks may be of a comparatively late date. They are usually composed of barren milky-white quartz.

Auriferous Occurrences in the Kraaipan Formation.

The discovery of gold at Abelskop, in the Transvaal, has given a great impetus to prospecting in the Mafeking Division, and the results obtained at Madibi are most encouraging.

A shaft has been sunk here to a depth of 150 feet, a short distance to the north of the railway and on the eastern side of the belt.

The material passed through consists of a biotite-chlorite schist, which is only found in the fresh condition at a considerable depth. It is always more or less crushed and decomposed, giving rise to white, pink, yellow, greenish, purple, and vermillion-coloured clays, stained with yellow or black limonite, and containing veins and lenses of ferruginous quartz.

This decomposed schist, penetrated by quartz veins, has a markedly well-banded appearance, and forms the auriferous material. It varies in width from three to six feet, and dips practically vertically.

At a depth of 140 feet the unoxidised material was reached, and the vein-stuff is heavily charged with pyrites.

The assays made at first gave very disappointing results, but lower down the values increased rapidly. Portions of the vein-stuff give remarkably high values, while the material elsewhere may carry only a few pennyweights; apparently the gold occurs in chutes.

Some samples taken by the Inspector of Mines, Captain Quentrall, and assayed in the Government Analytical Laboratory by Mr. J. G. Rose, gave an average value of 2 oz. 5 dwt. per ton, over a width of 3 feet 6 inches.

These results are from the variable zone of secondary enrichment. Deeper down, in the sulphide zone, the values will probably become lower, and possibly more uniform.

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The gold has been deposited from solution, together with pyrites and secondary quartz, along lines of fracture and crush. The ore-bodies will in all probability be found to have lenticular shapes, and the veins will pinch and widen both vertically and horizontally.

It would be of immense value, from an economic as well as from a purely geological standpoint, to determine the part played by the schists of the Kraaipan formation in the deposition of the gold. Up to the present, the auriferous occurrences are confined to the schist belts, and the veins in the granite have hitherto proved barren.

It is therefore of extreme importance, from a mining point of view, that the depth of the formation down the fissure to the granite should be known; this demands an accurate knowledge of the geological relations of the two formations.

The possibility that the fissure in the schist belt may become non-auriferous in the underlying granite is one that should not be lost sight of.

Gold has been found in some of the other openings at Madibi, and also at Kraaipan, Wodehouse Kraal, Gemsbok Pan, and on the Khunwana Reserve, in the Transvaal. The values are all low, but perhaps, as at Madibi, the gold content may improve with depth. No reliable records exist of the values obtained at Gemsbok Pan.

The results of prospecting show that, as a rule, the massive beds of magnetic quartzite never carry appreciable values, and the numerous veins of milky-white quartz, both in the formation and in the granite, are practically always barren.

Some of the cherts give values up to 6 dwts., but the rock is very hard and difficult to work in; shafts have been sunk in this material on Wodehouse Kraal. Some of the thin quartzites and earlier granulitised quartz-veins carry gold up to about 4 dwts.

The schists have in places been permeated by mineralising solutions; quartz-veins at Madibi are black with tourmaline inclusions, and minute tourmaline needles are abundantly disseminated through the various schists of that belt. Pyrites is sometimes met with, and is commonly pseudomorphed by limonite.

The softer strata are the ones that will with greater probability be traversed by lines of fracture, and therefore have been impregnated by mineralising solutions. They are, however, badly exposed, but accompany the magnetic quartzites of the central belt, and to a lesser degree those of the western belt.

The only way to test these beds is to cut deep trenches right across the strike of the belts, so as to expose the softer material; although more costly it is, in the end, more satisfactory than sinking numerous pits at haphazard.

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Position of the Kraaipan Formation in the Geological Sequence.

The lithological resemblance of these beds to the rocks known as Barberton beds and Swazi schists has already been remarked. Yet in the Mafeking Division the formation must be later than the granite, whereas in the Eastern Transvaal the granites are said to be intrusive.

According to Jorissen* the same is the case at Abelskop and Goudplaats, in the Bloemhof Division of the Transvaal; the magnetic slates there can hardly be other than part of the Kraaipan formation, but I do not feel quite satisfied that the granite is there intrusive in the formation. No granite veins have been found in the magnetic slates themselves, but only in the amphibolites and calc-chlorite-schists flanking them.

It is always possible, however, that the granite in Bechuanaland does not belong to the same period of intrusion as that in the Transvaal.

In the Prieska Division† of the Cape Colony there are certain magnetic quartzites which are rather different to the type usually met with in the Griqua Town beds. As they occur in the form of belts in the midst of the granite, and have a great resemblance to the magnetic rocks in the Mafeking Division, it is quite likely that they may belong to the Kraaipan formation.

That the Kraaipan formation is distinct from, and much older than, the Witwatersrand formation can hardly be doubted.

The latter is well developed in the Lichtenburg and Klerksdorp‡ Divisions, and is entirely different lithologically, while the alteration in the beds due to earth movements is there but slight, *e.g.*, the development of cleavage and the formation of sericite in the softer beds.

Petrographical Description.

(1) *Ferruginous Rocks.*—The quartzites range from pure white varieties to rocks in which the proportion of magnetite is about 40 per cent. The pure varieties are very rare, and always in very thin layers. The magnetic quartzites range from extremely fine-grained varieties with no visible quartz, to rocks in which the magnetite crystals attain a diameter of over a quarter of an inch. Haematite is commonly associated with the magnetite, but is always subordinate to the latter.

A thin section (1389) of a fine-grained variety exhibits the following features under the microscope:—The quartz-grains are elongated, and show granulitisation. They are usually bordered by brown ferruginous material, and form a matrix in

* Trans. Geol. Soc., S.A., Vol. VII., pp. 152-4, 1905.
† Ann. Rept. Geol. Comm. for 1899, p. 81.
‡ Molengraaff, Trans. Geol. Soc., S.A., Vol. VIII., p. 16, 1905.

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which are set crystals and crystal-aggregates of magnetite and plates of haematite. There are a few grains of corundum.

The varieties with actinolite present many interesting features, and sometimes the amphibole is accompanied by enstatite.

In sections 1390 and 1393 the actinolite is present in smaller amount than the quartz; in 1391 the mineral is more abundant, but in small prisms. In section 1392 the actinolite forms large plates, enclosing ophitically magnetite, haematite, and some quartz.

In the hand specimen these plates attain a length of over an inch. The density of the rock is 3.40. The actinolite is a pale greenish variety, without appreciable pleochroism. This is doubtless due to the abstraction of the iron, which has separated out in the form of limonite along the cleavages and cracks in the mineral. In the thin section 1394 the limonite renders parts of the crystals opaque. The actinolite shows very fine repeated twinning parallel to the orthopinacoid.

Some of the finely-pounded mineral, from which most of the magnetite was separated, gave a specific gravity of 3.01.

The enstatite is pale green in colour, slightly deeper in tint than the actinolite, with which it is often intergrown in parallel positions. In the hand specimen corresponding to 1392, the enstatite is abundant in dark green interlocking grains.

There is no clear indication of the origin of these magnetic rocks. Some of the poorer varieties must have been slightly ferruginous quartzites, but those rich in magnetite may possibly have originated from ferruginous limestones and dolomites.

The actinolite-enstatite-magnetite rocks are rather different in character from the actinolite-grunerite-magnetite rocks of the Lake Superior Region. Laterally they pass into magnetic quartzites; they are not in a region of great disturbance or one of igneous intrusion, and their origin can only be explained by the assumption of a lateral change in character of the original material. This may have been due to variation in the sediment deposited, or to chemical change in certain spots by mineralising solutions, prior to the metamorphism of the material.

Magnetite always predominates over haematite, except in some of the breccias, where the latter forms the cementing material, and where some of the brecciated material has suffered oxidation through the passage of solutions.

(2) *Cherty Rocks.*—Some varieties show clear chert, containing small irregular patches of carbonate, around which granules and flakes of haematite are concentrated. A jaspery variety consists of numerous little oval or slightly irregular bodies, about 0.03 of a millimeter in length, marked out by minute specks of iron ore, and set in a colourless mass of chert.

A section 1387 shows a dense ferruginous rock, which has been cracked in various directions, and the fissures filled in by clear chert. Section 1386 has a small amount of carbonate and flakes of either sericite or talc.

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Some of these cherts carry a little gold.

(3) *Schistose and Slatey Rocks.*—These show gradations from soft silvery micaceous schists through chlorite slates to hard green micaceous quartzites.

Calcareous schists are common along the Madibi belt. A section (1422) from near the beacon K 8 shows large pseudomorphs in pennine (chlorite) after some unknown mineral; these enclose portions of the groundmass. The latter is formed of granulitic quartz, chlorite, calcite, sericite, tourmaline, and abundant rutile, in the form known as sagenite.

Pyrophyllite rock occurs in two forms, either in crystalline aggregates like that already mentioned from Latham (Setlagoli), or massive and slatey, very much like a dark phyllite. The latter was obtained from a prospecting shaft about one-third of a mile north of the main shaft at Madibi.

Chlorite schist, with magnetite, was noted at Latham and a biotite-chlorite-schist at Madibi, the latter forming the casing of the auriferous material. The specific gravity of the latter is 3.12.

(4) *Calcareous Rocks.*—Some of these have been referred to, *e.g.*, the magnesian limestone from near Pitsani and the calcareous schists of Holland and Madibi.

At Pitsani, about a mile west of the Police Camp, is an outcrop of crystalline-limestone, very ochreous in places, and highly veined with calcite and quartz. The thin section (1431) shows large areas of siderite (including flakes of limonite, chlorite, etc.), calcite, quartz, chlorite, and abundant rutile.

The relations of this rock to the adjoining magnetic slates were not seen, owing to the overlying diabase.

A very similar rock was obtained close to the railway at Kraaipan, right in the upper part of the massive bed of magnetic quartzite. The junctions are sharp and irregular, and in the field the crystalline limestone resembles an intrusive mass in the Kraaipan formation. The occurrence may perhaps be explained as an originally lenticular mass of calcareous material, apparently thickened by close folding.

It differs from the Pitsani rock in containing less siderite and chlorite, and in having a feebly developed schistose structure.

V. The Ventersdorp Series.

The name Vaal River System was first and very appropriately applied by Molengraaff* (following Cohen) to the great thickness of volcanic rocks that overlie the Witwatersrand series in the Transvaal, and are older than the Black Reef series. In addition to lavas, they include as well breccias, conglomerates, and other rocks, both of sedimentary and igneous origin, and cover a vast area in the south-western corner of the Transvaal.

* Molengraaff, "Geology of the Transvaal," p. 19, 1904.

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The equivalent term Ventersdorp beds was introduced by Hatch,† in describing the development of this formation in part of the Potchefstroom District.

The name *Ventersdorp Series* has been generally adopted, and will be used throughout this Report.

In the Vryburg Division the Zoetlief beds are separated by a marked unconformity from the overlying diabases and amygdaloids of the Ventersdorp series; still, as they include quartz-porphyries, cherts, grits, etc., very like those described from the latter formation, it seems preferable to group the two formations together, rather than raise the Zoetlief beds to the rank of an independent series. With them in consequence will also be placed the sandstones and conglomerates of Botman's Poort.

1. *The Zoetlief Beds.*

These rocks form a belt of high ground to the north-west of Vryburg, running from Zoetlief in the north through Klip Fontein. The width of the outcrop is usually from four to five miles.

The lowest beds, which, as a rule, are only exposed in wells, consist of arkoses and thinly bedded quartzites, which rest directly upon the granite.

On the farm Hope Vlei a well has been sunk in horizontally lying greenish quartzites, thinly bedded, and with flakes of brown mica on the bedding-planes; similar material was obtained in a well on the farm Klip Fontein, about a mile to the west.

On Wilde Beest Pan there are outcrops of thin-bedded and fine-grained quartzites, dark grey to buff in colour, which dip at an angle of about five degrees to the south-east. To the north these quartzites are evidently not represented, and on Leeuw Bosch and Kameeldoren there are wells which expose a considerable thickness of arkose and re-constituted granite wash. The material varies from coarse pebbly stuff, with abundant fragments of quartz, to fine white pipe-clay, with the bedding planes marked out by scales of brown and white mica.

Some of the intermediate varieties have a remarkable resemblance to the decomposed biotite-gneiss found to the north, and it is only by the finding of bands of finer or coarser material that the clastic nature of the rock becomes apparent.

The junction with the granite is never seen, and the presence of the latter is only made evident through the sinking of wells.

The whole of the formation ends abruptly on Vogel Vlei, and apparently the granite has been brought up against the beds by means of a fault striking north-west.

† Hatch, Trans. Geol. Soc. of S. Africa, Vol. VI., p. 95, 1904.

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At the Saltpan is an area of rocks which evidently belong to the base of this formation. The dip is generally at a low angle to the south, and the beds crop out all round the pan, and also at points within it.

The rocks consist of dark grey or greenish shales and flagstones, with flakes of biotite on the bedding planes; they are beautifully ripple-marked, and show numerous casts of worm-burrows. The flagstones are easily extracted in slabs six feet or more across, and by being placed edgewise in the ground can be utilised in constructing kraals and fences.

On the east side of the pan are coarse greenish felspathic sandstones, while a typical arkose is found in a well a mile and a half north of the Saltpan; the strata and the granite are mostly hidden by red soil or calcareous tufa. The flagstones are succeeded by trachytic lavas and breccias, forming the western boundary of the pan; these are followed by a hard grey quartzite.

The relation of these beds to the ferruginous cherts forming the ridge to the west of the pan is not seen, but it is not improbable that the two formations are separated by a fault having a downthrow to the east.

The middle portion of this formation consists entirely of acid and intermediate lavas: quartz-porphyries (rhyolites), trachytes, and allied rocks. Owing to their ability to resist weathering, the quartz-porphyry forms dome-shaped hills and rounded ridges.

The *quartz-porphyries* vary in colour from light pinkish to greenish-black, and contain blebs of quartz and phenocrysts of orthoclase. On the farm Kameeldoren holocrystalline patches occur in the porphyry.

At Zoetlief the quartz-porphyry passes insensibly into orthoclase-porphyry, a dark green rock, which is characterised by the presence of the orthorhombic pyroxene enstatite.

In slide 1381 parts of the enstatite crystals are still fresh, but in the other sections this constituent is replaced by chlorite and calcite, in 1382 by epidote.

The porphyritic orthoclases are much altered, and in fact most of the specimens show a silicification both of the felspar and the ground mass. A little biotite is sometimes apparent.

Trachytes are not so well represented. They are vesicular or drusy rocks, and are to a great degree silicified.

These rocks were found at O'Reilly's Fontein and at the Saltpan; at the latter locality they are associated with trachytic breccias.

An *andesite* was obtained from a well on O'Reilly's Fontein, and there seems to be a continuous passage upwards from andesite through trachyte to rhyolite (quartz-porphyry) on this farm.

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The thin section (1385) shows a highly vesicular rock, with the cavities lined by quartz and chlorite and filled in with calcite. The felspars are in laths, and enstatite is probably represented by little chlorite pseudomorphs. There is some brownish glass in places and a little magnetite.

The uppermost division consists of a variable series of dark quartzites and flagstones, which grade into cherts.

At Zoetlief, where they reach their maximum development, these quartzites and sandstones are greenish-black in colour, with red and brown streaks of cherty material. In a well 95 feet deep at the homestead there are, in addition, greenish flaggy grits, with flakes of brown mica. To the south they are followed by shales, flagstones, and quartzites, often ripple-marked, dipping at an angle of about five degrees to the south-east. Towards the top of the series is a bed of highly vesicular lava, greenish to buff in colour, and probably trachytic in composition. It is succeeded by similar strata, which are often rather flinty.

The whole formation on Zoetlief is affected by slight flexures, having a trend about north-east, *e.g.*, parallel to the fault on Vogel Vlei.

On the farm Karree Bult, close to the Saltpan Siding, there occurs in the midst of the diabase and amygdaloid a small area of shales and flagstones resembling the rocks at Zoetlief.

Some of the shales are very soft, and are accompanied by thin layers of light-grey limestone.

The quartz-porphyry ridge on Leeuw Rand and Schat Kist is overlain by rocks belonging to this division. On Leeuw Rand a belt of cherty rock about 30 yards wide and 400 yards long intervenes between the quartz-porphyry and the diabase, and has a dip of from 30 to 40 degrees eastwards.

These cherty rocks range from colourless to milky-white, brown, red, and black varieties, sometimes well banded, which grade into hornstone or fine-grained quartzite. Some of the chert contains fragments of quartz-porphyry, and these beds appear to consist principally of acid tuffs and breccias that have been silicified. It has already been noted that the quartz-porphyries and trachytes have also been much silicified, an alteration that extends down almost to the base of the volcanic series. On Leeuw Rand the porphyry is traversed by numerous veins of quartz several inches in width, with a north and south strike, and often extending for no small distance. On Schat Kist the same rock is ramified by veins of chalcedony, from colourless to jasper-red, and mostly vertical.

Probably these represent fissures, up which heated waters carrying silica in solution rose. This is a process that not infrequently marks the period following the cessation of the eruption of acid lavas.

Further to the south on Schat Kist, close to the beacon, the cherty rocks reappear, with a general dip of from 5 to 10 degrees

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eastwards. Owing to their extreme hardness, they form a ridge rising to a fair height above the surrounding flats of diabase.

In the midst of the massive cherts, which are at least 150 feet in thickness, there is a thin stratum of hard green sandstone, from massive to flaggy, and sometimes ripple-marked. It is crowded with little grains of glassy quartz, and when weathered is very ochreous.

North of Mafeking, on the farm Sunnyside, there is a low ridge known as the Signal Hill, which is formed of rocks most conveniently grouped with the Zoetlief beds.

The great bulk of the material consists of flinty rhyolitic and trachytic lavas, with which are associated breccias, tuffs, and conglomerates, often much silicified; there are also dark banded flinty rocks, cherts, cherty breccias, flagstones, and quartzites, the majority of which weather with a light brown or yellow exterior. The dip of the formation varies from 20 to 60 degrees, and the strike is a little west of north.

On the north-west side is much red sand, and probably the strata either rest upon or are faulted down against the granite. The eastern and southern boundary is produced by low ground, and a few well-sections show diabase. The discordance both in dip and strike between the two formations is clearly marked.

Relation of the Zoetlief Beds to the Diabase Formation.

The various outcrops all indicate a considerable unconformity between the two formations.

The Zoetlief beds have been somewhat disturbed and greatly denuded prior to the pouring out of the diabasic lavas. The quartz-porphyry and cherts under denuding influences produced marked ridges, and consequently were not buried by the lavas to the same depth as other horizons of the formation. On Middel Kop a well passed through the diabase into the porphyry. On Vogel Vlei the basic lavas apparently cross from the Zoetlief beds on to the granite without being affected by the fault that separates the two latter formations.

At Schat Kist the veins of quartz and chalcedonic silica which are abundant in the porphyry are wanting in the diabase. The discordance north of Mafeking has already been noticed.

The only place where there is no marked divisional line is at the Saltpan; this is due both to the paucity of outcrops and to the coming together of two sets of vesicular volcanic rocks.

2. *The Botman's Poort Sandstones.*

South-west of Brussels Siding, at the farm Botman's Poort, on the Transvaal border, there are certain sandstones which partly bridge over the gap between the Zoetlief beds and the diabase. The strata appear to form a dome a few miles in

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diameter, situated almost entirely in Transvaal territory. The rocks dip under the diabase on the north-west at angles of about 30°, and on the south and north at lower angles. Whether these beds are conformable with the overlying diabase is uncertain, and can only be ascertained by an examination of the area over the border. On the north of the farm, however, there are so many small outcrops of quartzite in the diabase and amygdaloid as to lead one to the view that there is an interbedding of igneous and sedimentary material. The sandstones vary from fine-grained varieties, often approaching quartzites, to very coarse-grained arkoses and conglomerates, the material being in some places friable and in others hard. Black quartzites, cherty quartzites, and cherts occur very often, and the beds are in places traversed by quartz veins from thin stringers up to reefs several inches wide.

The arkose and conglomerate occur at the bottom of the (visible) formation, and weather into great rounded masses just like granite. There is an abundance of large quartz-pebbles, masses of slate, and boulders up to four or five inches in length, principally of quartz-porphyry, but granite and quartzite are also present. There must be fully 350 feet of strata visible on this farm, and the actual base of the formation is not seen.

The abundance of quartz-porphyry in the form of pebbles points to the Zoetlief beds as their probable original source, in which case the Botman's Poort sandstones will be later in age than that formation.

Close to Vryburg, on the farm Bernau, there are two patches of sandstone, which may conveniently be grouped with those of Botman's Poort.

The western patch (fig. 4) is about 50 yards across, and the strata dip from 10° to 15° in a direction 30° east of north; the second patch, about 300 yards further to the north-east, has about the same size and a dip similar in amount and direction.

The rock consists of a white or cream-coloured sandstone, soft and sometimes friable, but in places darker in colour and quartzitic. The material can be removed in large blocks; it is almost a free-stone, and has been utilised as a building stone. Round about are exposures of diabase, amygdaloid, and breccia, and the only explanation of the manner of occurrence of these sandstones is that the volcanic rocks rest unconformably upon them.

On the railway about two miles north of Vryburg Station there is an exposure in the midst of the Dwyka boulder-clay of similar sandstones, which are here horizontal. Diabase is seen a few hundred yards further north.

3. *The Diabase Formation.*

In this term is included compact and amygdaloidal diabases, volcanic tuffs and breccias, conglomerates, grits, sandstones, and

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shales. We may therefore in the following account consider separately those rocks that are of igneous and of sedimentary origin respectively.

Distribution.—The formation covers a considerable area to the north and north-east of Vryburg, and is found again to the north, east, and south of Mafeking. The former extension of the formation westwards is indicated by the existence of small outliers between Setlagoli and Mosita, in the Mosita valley, at Mosadiapitsi Kopjes, and at Pitsani. In a southerly direction the formation extends along the Transvaal border into the Taungs district.

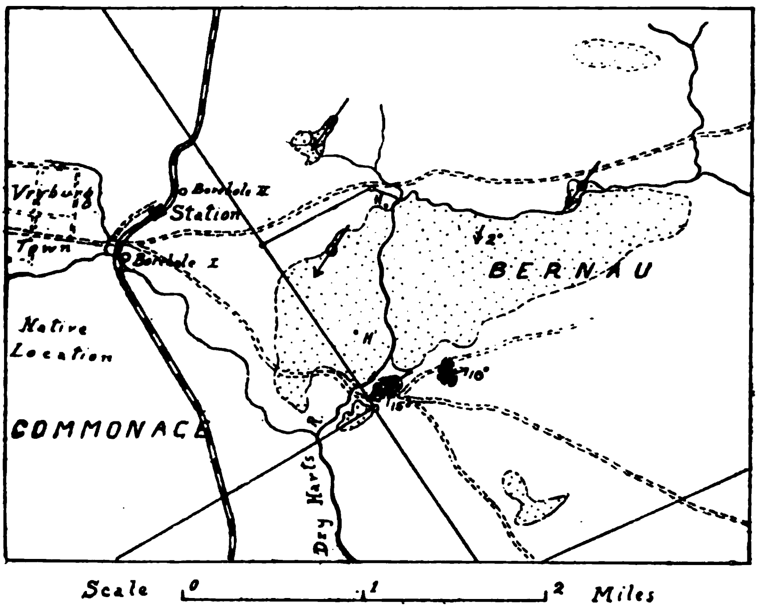

FIG. 4.—Plan showing positions of glaciated surfaces east of Vryburg town. The areas dotted are formed of volcanic rocks, those shaded indicate sandstone, while the unshaded remainder represents Dywka boulder-clay.

(A) *The Volcanic Rocks.*—These constitute the great bulk of the formation, and form wide flats, so that, as a rule, the rocks are not very well exposed.

In the lavas bedding-planes can very seldom be made out. Flow-structures are finely developed, and it is usually uncertain whether the banding, due to rows of elongated vesicles, is to be construed as indicating the actual dip of the bed or merely the lines of flow in that particular stratum. Judging, however, by the frequency with which certain areas are found covered with little knobs of rock, all having the same texture and character, it is probable that in very many cases the dip is approximately coincident with the slope of the surface of the country, *i.e.*, the dips are low.

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The thickness of the formation must be considerable, but no estimates can be made. At Vryburg a borehole (fig. 4, No. II.) was still in diabase at a depth of 531 feet.

The lavas are dull-green rocks, which usually weather with a pinkish or purplish-brown tint. The rock is either compact or vesicular, and the cavities are lined by chlorite or quartz and filled with either agate or chalcedony; the latter is often bright red, like sealing-wax.

In composition the lavas appear to be most frequently andesitic in character, varying from acid to basic varieties, but the rocks are nearly always altered to a considerable degree. Some specimens were glassy lavas, the majority were fine-grained and crystalline, and in one place a porphyritic type was noted.

The felspar is usually the only recognisable mineral constituent; the ferro-magnesian mineral was probably augite, but is usually replaced by chlorite or calcite and epidote. The last named may even be developed in the felspars. The ilmenite is changed to leucoxene. Most of the rocks show silicification to a great degree, and the ground-mass and even the felspar laths are replaced by chert, which polarises as a mosaic.

A rather unusual type of rock occurs on the banks of the Molopo River at the Police Camp, Pitsani.

The lava shows "pillowy-structure," and consists of rounded or ellipsoidal masses, vesicular in the interior, but with dark compact exteriors. They vary from six inches to two feet in length, and are embedded in a dark green igneous ground-mass. The rock passes laterally into very fine-grained diabase and diabase-tuff, and rests upon granitic-gneiss. Further down the river it partly covers magnetic slates.

Another rather unusual type is a variolitic andesite from the farm Faith (Mosita). The thin section (1419) shows a mass of fibres and ragged plates of pale hornblende, commonly arranged in bundles. The ground mass is water-clear felspar.

The diabase-tuffs and breccias commonly form a slight feature in the landscape. Breccias are developed along the river banks on Bernau, just east of Vryburg, and are accompanied by fine-grained tuffs.

The rocks are composed of fragments of diabase of various types, but there has been silicification of the material, and the matrix is chert, with little plates of chlorite and crystals of calcite.

North of Mafeking volcanic breccias form the ridge along the border on Trumpeter's Post, and the formation extends eastwards into the Transvaal. The rock recalls the conglomerates of Mafeking in its mode of weathering, and, like it, includes fragments of granite and gneiss, but not so abundantly. The inclusions consist principally of diabase and amygdaloid, from dark to flinty light-coloured varieties.

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There are numerous transitions, both laterally and vertically, from lavas into breccias. A prospecting shaft shows a peculiar black flinty rock, occasionally vesicular, and evidently originally a glassy lava.

A thin section (1429) of the breccia shows that all the glassy base and sometimes some of the minerals as well has been replaced by chert and rhombohedra of calcite. Fragments of what is now clear chert may originally have been volcanic glass.

The flats to the north are underlain by granite, so that the breccias of Trumpeter's Post apparently rest directly upon that formation.

(B) *The Sedimentary Rocks.*—These occur at two localities, *e.g.*, Mafeking, and between Setlagoli and Mosita.

(i) The Mafeking occurrence has been referred by several observers to the Dwyka conglomerate; a detailed account has been given by Passarge,* while a petrographical description has been supplied by Philippi.†

It seems rather surprising that so many observers should have considered the Mafeking conglomerates to be of Dwyka age, for the soft northern boulder-clay is entirely dissimilar to the extremely hard rock found here; the view that the hardening is due to silicification during Tertiary times is unsupported, as far as I can see, by any field evidence.

The conglomerate forms an outcrop fully three-quarters of a mile in width, upon which the town of Mafeking is built. There are fine exposures in the native stad on the banks of the Molopo. The rocks forms great rounded masses, often many feet in height, between which the native huts have been built.

In the central portion of the outcrop the matrix of the rock is very gritty, and the bedding is well shown; the dips vary from 10 to 20 degrees towards the east. The boulders enclosed sometimes lie with their long axes parallel to the bedding planes, but not always, and they are not arranged in layers according to their sizes.

The actual base of the conglomerate is not seen, but it is underlain by no great thickness of diabase, and that in turn by granite and gneiss, seen in wells, also further down the valley of the Molopo. The conglomerate passes upwards into a rock, which becomes more igneous in character, *i.e.*, a volcanic breccia, and this is succeeded by the diabases and amygdaloids which outcrop south-east of the town.

In a northerly direction the conglomerate belt can be traced for a few miles by occasional boulders in the soil, and the same is the case to the south.

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* Passarge, S., Zeits der Gesellschaft für Erdkunde zu Berlin, Band XXXVI., p. 22, 1901.

† Philippi, E., Zeits. der Deutschen Geolog. Gesellschaft, Band LV., Heft IV., p. 314, 1904.

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It is evident that the outcrop represents a lenticular deposit of no very great extent. Estimating from the dips visible, the thickness of rock must be fully 1,000 feet, but it is quite possible that the true inclination of the deposit is not very great, and that the apparent dips represent a kind of false-bedding, for it is hardly likely that coarse conglomerates and volcanic breccias would be spread evenly over any large area.

Petrographical Description.—The inclusions range in size from pebbles up to boulders about a foot in length. As a rule they are well-rounded, but sometimes, though not commonly, the angles are quite sharp; the fragments in the matrix are very frequently angular. The rock is extremely hard, and it is almost impossible to extract the boulders from it. The inclusions consist chiefly of granite and gneiss, various diabases and amygdaloids, quartz, and less frequently grits and hard slates.

In thin section (1426) under the microscope we find angular to rounded grains of these various rocks set in a pale greenish ground-mass of feebly doubly-refracting opaline silica. The silicification has extended through the inclusions, and has especially replaced the glassy base of the diabase; this recalls what has been already noted in the description of the diabase-breccias. The granite, and minerals derived from it, appear to have escaped the alteration. A certain amount of calcite accompanies the silica.

(ii) Between Setlagoli and Mosita is an outlier of the diabase formation showing peculiar features. On Salem, Kgoro, and Zwart Laagte are diabases and a great development of diabase breccias and tuffs, which fill up a basin in the granite; the hill supporting the beacon M. 6 on Bosch Kop is composed of these rocks.

In the valley traversing Massouw and Bosch Kop these volcanic rocks are replaced by coarse greenish sandstones, very hard and conglomeratic in places. The dips are low, usually about 5° north-north-east.

In the north corner of Mooi Plaats there is some high ground composed of similar conglomerates, but the rock is here crowded with pebbles, which, when weathered out, strew the surface of the ground.

Petrographical Description.—While the pebbles in the conglomeratic sandstones of the valley are commonly from six to eight inches in diameter, those on Mooi Plaats may attain a length of eighteen inches. The boulders are usually well smoothed and rounded, but sometimes they are sub-angular.

The nature of the included material varies in different parts of this area, but granite, gneiss, quartz-porphyry, diabase, amygdaloid, quartzite, quartz, and banded cherts, ferruginous rocks, and jaspers are most abundant.

In thin section (1416) the rock shows a great resemblance to the Mafeking conglomerate, but the silicification has not been so complete.

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The bulk of these inclusions have been derived from rocks which are now exposed within a short distance of the basin; for example, the hill known as Vogelstruis Kop, close at hand, is formed of cherts and ferruginous rocks similar to those found as pebbles in the conglomerates; the quartzites and quartz-porphyries are not represented in the immediate neighbourhood.

To the south-west are extensive sand-covered tracts, which I suspect are underlain by granite. On the farm Bosch Kop a borehole put down by the Public Works Department showed quite an unexpected series of beds.

The section reveals 80 feet of dark indurated shale, 20 feet of slightly micaceous shale passing into fine-grained blackish-green quartzite, 106 feet of coarser-grained quartzite with little muscovite flakes, 114 feet of hard black shales, and 48 feet of hard rock—either quartzite or diabase, but no sample of the core was preserved.

Apparently the finer-grained material, which is at least 400 feet thick, occurs towards the bottom of the basin, and is succeeded by the coarser-grained sandstones and conglomerates seen towards the north.

As the dip of the strata is always low, it is difficult to account for the form of this basin as being due to earth movement solely. Round about, on Vogelstruis Kop, Salem, Zwart Laagte, and Rooi Kop, the older rocks are exposed either naturally or in wells, and a patch of diabase is found on the edge of the basin at the north-western corner of Hartebeest Pan.

Either the basin was one with unsually steep sides and deeply excavated, or else it owes its origin to some extent to faults; in the absence of good exposures it is impossible to decide which is the more likely view.

Relations of the Diabase Formation to the Underlying Rocks.

Everywhere a great unconformity is apparent, and the positions of the various outcrops supply us with considerable information as to the conditions under which the formation was produced.

The later earth-movements were never very extensive, and the surface underlying this formation must have possessed to a considerable degree the features that are now still evident.

The formation must have been laid down on a very diversified surface; the rocks of the Kraaipan formation formed the hill-ranges in those days, and in consequence were not buried to the same depth as the other and lower-lying formations. Denudation has removed the diabase from these ridges either partially or completely, while the presence of outliers of diabase in some of the present river valleys, *e.g.*, the Mosita and the Madiban, shows that the ancient topographical features remain but partially modified at the present day.

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It is possible that in places the diabase flows were insufficient to completely bury the ancient ridges—for example, at Zoeteinval, where the Black Reef series rests upon a former elevation composed of granite and magnetic rocks, partially surrounded by diabase lavas. These features may, however, be equally well accounted for by denudation of the diabase preceding the deposition of the Black Reef quartzites.

It seems most likely that the greater portion of the volcanic material was laid down sub-aerially, for there is great variation in the rocks and a general absence of marked bedding both in the lavas, agglomerates, and tuffs.

In certain areas sedimentation appears to have gone on uninterruptedly with the formation of shales, sandstones, and conglomerates; the size and smoothness of the boulders probably indicates river or beach-gravels; some of the pebbles must have been brought from considerable distances. Finally, the area must have been submerged so as to allow of the deposition of the Black Reef series.

The great amount of volcanic breccia and agglomerate met with in places points to the vicinity of volcanic vents, but I have not yet been able to locate anyof these with certainty. There is also a marked absence of dykes from which the lavas may possibly have issued, as in the case of fissure-eruptions. The only diabase dykes yet found differ entirely in petrographical characters.

VI. The Black Reef Series.

The quartzitic rocks lying at the base both of the Campbell Rand and the Malmani dolomite must be the equivalent of the Black Reef series of the Transvaal.

The Black Reef series is essentially a quartzitic formation, and one that in places becomes conglomeratic. The quartzites are often accompanied by slates and flags and by interbedded diabase flows.

Distribution.

(1) *Vryburg.*—Within the area surveyed the Black Reef series has an irregular outcrop, which runs from Massouw's Kop to Vryburg, crosses the Dry Harts River on Rosendal, makes a turn to O'Reilly's Pan, and then curves round and extends southwards to Dry Harts Siding. It forms the north-eastern extremity of the gentle syncline of the north end of the Kaap Plateau. Owing to their hardness, the quartzites form a narrow belt of high ground; just south of O'Reilly's Pan the strata are horizontal, and have produced a wide tableland.

The quartzites are usually light-coloured rocks, commonly false-bedded, and they pass into dark grey or greenish rocks, with scattered pebbles of quartz, chalcedony, etc. Calcareous

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quartzites are sometimes represented, as on the farm Lange Rand near the Dry Harts River.

Flagstones are very common—thinly bedded quartzites, which are sometimes micaceous and often very finely ripple-marked. These may pass into greenish fissile sandstones or shales, which weather deep red along joints and bedding planes, owing to the production of hydrated iron oxides.

Such shales are well exposed in numerous little quarries at the gaol, Vryburg. Worm casts and other markings, probably due to organisms, are occasionally visible.

The conglomerates are rather unevenly distributed, and over large areas they may be unrepresented. The best locality for studying them is at Vryburg, along the ridge on which the Hospital has been built. Usually the pebbles are collected together to form thin bands, never continuous for any distance; just below the hospital there is a bed of conglomerate many feet thick.

The pebbles vary from one to three-quarters of an inch in diameter, but occasionally larger ones are present. The greater number consist of either colourless or milky quartz, but chalcedony and banded agate are abundant, while quartzite, hard slate, banded jasper, and diabase are also found.

It is evident that the Diabase formation has contributed largely to the formation of these deposits, and no doubt the dark green colour of the shales and quartzites is chiefly due to comminuted diabasic material. It must not be overlooked that volcanic ash may to a considerable extent have been incorporated with the sediments.

The conglomerates at Vryburg have been prospected for gold, but unsuccessfully; their gold content is very low, and the pebble beds are irregularly developed and unevenly distributed.

The thickness of the formation varies from about 150 feet to close upon 200 feet.

(2) *Outliers at Zoeteinval and Blink Klip.*—The outlier of Zoeteinval is fully three miles in length, with a rather irregular outline; it forms the highest ground in this area (4,490 feet), and is a point on the watershed from which a number of stream-courses radiate.

The beds are in some places disturbed by small flexures, but as a rule dips are low.

The quartzites are often either ferruginous or cherty, and are traversed by occasional veins of chalcedonic silica carrying pyrites.

In the extreme northerly corner of the farm the quartzites abut against the highly folded magnetic rocks of the Kraaipan formation, and contain small fragments derived from these older beds.

Two small outliers of quartzite occur resting upon amygdaloidal diabase in the valley traversing Blink Klip.

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(3) *Mafeking.*—The Black Reef series just enters from the Transvaal at a point immediately south of Rooigrond; it forms a small portion of the south-western rim of the great basin of the Marico area.

The formation consists of from 30 to 40 feet of coarse quartzite, sometimes conglomeratic with pebbles of quartz and agate, passing into dense black quartzites, weathering to a reddish brown colour. Slaty beds are now and then present. The outcrop is very narrow and inconspicuous, and the beds have a dip of about two degrees to the east.

Relations of the Black Reef Series to the Underlying Formations.

In the Vryburg area there are only three localities where the contact with the underlying diabase can be made out.

At Massouw's Kop, where the strata are admirably exposed, the quartzites rest upon a slightly undulating surface of diabase, but the latter appears to be perfectly conformable as regards dip with the former.

On Bernau the two formations have the same dip, though the actual junction is hidden.

On Schat Kist and on Lange Rand the quartzites again rest on the diabase, but the dip of the latter cannot be made out.

At Zoeteinval the Black Reef series rests upon three formations, *i.e.*, the granite and gneiss, the magnetic quartzites and cherts of the Kraaipan formation, and the diabase.

At Mafeking the diabases and the quartzites have the same easterly dip.

Volcanic Activity during the Deposition of the Series.

At Vryburg just behind the gaol there is interbedded in the quartzites and shales a flow of diabase about 8 or 10 feet thick, and amygdaloidal in places.

In the gorge of the Dry Harts River, on the farm Rosendal, a sheet of diabase from 10 to 15 feet thick occurs on a horizon about 40 feet below the summit of the quartzites, and can be followed away from the river for some distance. Though usually a compact rock, it is amygdaloidal towards its upper limit, and the junction with the overlying quartzite is exposed on the left bank of the river.

The Black Reef series is always succeeded by a sheet of volcanic material from 70 to 100 feet in thickness, followed immediately by the dolomite.

This is well exposed on Zand Vlakte along the road from Vryburg to Genesa, the rock being highly amygdaloidal.

The best section occurs in the Dry Harts River gorge on the farm Waterloo, close to Tiger Kloof Siding; the dip of the beds is from 3° to 5° to the south, *i.e.*, downstream.

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The great bulk of the material consists of a basic lava, often markedly amygdaloidal, and showing elongation of the vesicles and other fluidal structures. In places it is brecciated or may contain fragments of quartzite, diabase, dolomite, chert, etc., passing into an agglomerate; irregular bands of flinty rock traverse the mass in different directions. Some of the flows are more acid than others.

On the left bank of the river there is an irregular bed of dolomite intercalated in the upper portion of the lavas.

The base of the Campbell Rand dolomite rests in a perfectly unaltered condition upon the upper surface of the lavas, but at the junction there is often a layer of red banded chalcedony, up to eighteen inches in thickness, and due to infiltration.

All this points to contemporaneous volcanic action; Mr. Holmes,† however, has maintained that the amygdaloid is a variety of intrusive diabase.

To the west, on the farm Sweet Home, there are extensive exposures of this volcanic sheet.

Immediately to the east of Brussels Siding there are good outcrops of the volcanic rock immediately below the dolomite. The former is in places a breccia, and towards its upper limit has lenticular masses and thin layers of dolomite intercalated, while fissures in the lava and breccia are filled in with similar material; the dolomite is quite unaltered at the contacts. Again on the farm Lange Rand we find on the ridge overlooking the railway another clear section showing the dolomite resting upon a slightly uneven floor of diabase and diabase-breccia.

There can be no doubt that we have had the formation of a series of flows, accompanied by volcanic breccias, during the deposition of the Black Reef series and the Campbell Rand dolomite. That this volcanic action was widespread is shown by the occurrence of beds of similar igneous material at the base of the dolomite on Sweet Valley, to the south-east of Mafeking.

Relation of the Transvaal System to the Ventersdorp Series.

In this area there appears to be an unbroken sequence from the Diabase up to the Dolomite, sedimentation having been contemporaneous with volcanic outbursts.

Whether there is a break at the base of the Black Reef series is not clearly indicated in this district; certainly the diabases have by their denudation contributed largely towards the forming of the overlying rocks.

In the Transvaal an unconformity is clearly marked in several localities, but a brief examination of the geological map of that Colony shows that over its entire western half the Black Reef

† G. G. Holmes, "Geology of a Part of Bechuanaland West of Vryburg." Trans. Geol. Soc., S. A., Vol. VII, p. 131, 1905.

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formation always rests upon rocks belonging to the Ventersdorp series. That such should be the case over such an enormous area shows that the break between the two formations cannot be of very great magnitude; those places where the unconformity is most marked may be of merely local importance. In Vryburg and Mafeking the relation between the two formations is a very intimate one, and further work to the south will be required to decide the exact value of the supposed unconformity

VII. The Campbell Rand Formation.

Only a small portion of the vast area occupied by this formation was examined, comprising therefore the lowest few hundred feet of beds only. The formation consists principally of dolomitic limestones, but there are thin beds of magnesian limestone, calcareous sandstones, quartzites, and shales.

In the Transvaal the formation is termed simply "The Dolomite," but most of the specimens from the Cape Colony effervesce to a greater or less degree with cold dilute hydrochloric acid.

The rock is bedded in layers of a foot or more in thickness, and contains blackish chert in the form of thin bands, lenticles, veins, and concretions which are oval or irregular in outline.

It weathers in the usual way with a rugged deep brown surface, and jagged portions of dolomite and chert project above the surface of the ground. Percolating water has often dissolved away the rock along lines of jointing so that deep fissures result, which are usually filled in from above with soil or calcareous material. Such channels are finely exposed along the railway in the ascent from Brussels Siding to Tiger Kloof.

Oolitic dolomitic limestones are of frequent occurrence, but no traces of organisms can be made out in them; some beds contain small fragments of dolomite, perhaps rolled portions of material in the course of deposition.

At Kameel Fontein, south-west of Vryburg, there are some soft light-coloured calcareous sandstones containing irregular little cherty fragments that much resemble organic remains.

From Warrants Vlakte, west of Vryburg, a specimen of calcareous sandstone shows in thin section (1361) under the microscope little spheres of chert that are possibly of organic origin.

VIII. The Dwyka Formation.

Shales and boulder-clay belonging to this formation cover a fairly large area around the town of Vryburg. Patches also occur to the south and south-east of the town. To the north no outliers of this formation were observed, the conglomerates of Mafeking belonging to the Ventersdorp series.

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The rocks of the Dwyka formation are hardly ever naturally exposed, but they are fortunately in many cases revealed by wells and other artificial openings; their presence underground is almost invariably indicated by the number of large boulders foreign to the neighbourhood resting upon the surface of the ground.

The Dwyka "boulder-clay"—it can hardly be termed a conglomerate here—is typically a soft argillaceous material, bluish or greenish when fresh, but commonly, and to a considerable depth, weathered to a brownish clay.

This clay is soft enough to be excavated with pick and shovel, but now and then harder bands are met with having a certain amount of carbonate of lime as cementing material.

The boulder-clay gives a yellowish soil, which is covered over by, and impregnated with, calcareous material.

In two wells within the town of Vryburg a stratum of tough clay was met with quite free from boulders or pebbles, the only inclusions being minute grains of quartz sand.

This bed of clay is beautifully banded in different shades of red, purple, brown and green, but the rock fails to part along the bedding-planes, and breaks with a conchoidal fracture. It is about twelve feet in thickness, is overlain by normal boulder-clay, and rests upon a hard light-grey shale that merges into a very tough bedded conglomerate containing large striated boulders.

Inclusions in the boulder-clay are very numerous, blocks of diabase and amygdaloid being most abundant; after these come granites and gneisses, massive conglomeratic and sheared quartzites, dark grits, diabase-breccias, magnetic quartzites, jaspers, cherts, and dolomitic limestones.

The boulders are often from six to eight feet in length, and are finely striated. The smaller pebbles do not usually show the effects of glaciation quite so well. Possibly many of these inclusions have been derived from rocks at one time *in situ* not very far toward the north-east, and have not in consequence been transported any considerable distance.

East of Vryburg (fig. 4) there are glaciated surfaces, and in several localities smooth and well-rounded hillocks of diabase are exposed in the midst of the boulder-clay.

The directions of these striae vary from S. 35° W. to S. 66° W., thus indicating a general movement of the ice-sheet from north-east to south-west.

At Vryburg the formation covers an area about six miles in diameter, and sends an arm about two and a half miles wide to O'Reilly's Pan, a distance of ten miles in a north-easterly direction. Its southern boundary runs along the base of the Black Reef quartzites, and conceals the junction of that formation with the underlying volcanic rocks.

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The boulder-clay rests in a hollow scooped out of the older rocks: that is, the depression represents a glaciated rock-basin; everywhere to the south there is a barrier of quartzite, though it is just possible that an outlet existed west of the railway, in the dolomite area; in this direction the rocks are concealed by a thick deposit of calcareous tufa. The Dry Harts River runs in a deep gorge, not more than 150 yards wide, cut through quartzites; there seems to be no boulder-clay in this channel, and it is very probable that the present river alone is responsible for the excavation.

The floor of the Vryburg glaciated-basin is apparently very uneven, and in several places it projects through the boulder-clay. All the wells in Vryburg have been sunk in this formation, and though some have attained a depth of 90 feet, in no case has the bed-rock been reached.

Of two borings at the Railway Station, Number II. (fig. 4) passed through 144 feet of shale and boulder clay before penetrating the diabase, while Number I. was still in boulder-clay at 182 feet.

On the farm Gleef two wells have proved at least 50 feet of similar material. Water is fairly abundant in the boulder-clay, and a considerable supply is obtained from it in Vryburg; but the quality of the product is not good, the water being very hard and slightly brackish.

Patches of boulder-clay are met with along the railway between Vryburg and Brussels Siding. South-eastward of Vryburg there is a large grassy flat, extending from Hartlip as far down as Rosenberg, and bounded on the east by the diabase of the Transvaal border and on the west chiefly by quartzites.

On the farm Weltevreden there is a small outcrop of till crowded with boulders, while on the farm Van Vreda Dwaling are two wells in shales; further up the hillslope and just below the trigonometrical beacon a well affords a section through the shales into boulder-clay underlying them.

At Malalaring, on the Transvaal border, there are, in close proximity to the diabase, several wells in soft grey and black shales. A little further south is a low ridge, evidently formed of boulder clay, for the red sandy slopes are strewn with large boulders, chiefly of quartzite, quartz-porphyry, and diabase. Within about 150 yards of the Police Camp there is a sill of Karroo dolerite, at least 50 yards wide across the outcrop, cutting through the boulder-clay in a north-easterly direction. The wide flats of Blaauwbosch Kuil, Borthwick, etc., although no outcrops are visible, are probably underlain by the Dwyka formation.

Another very interesting locality is the Dry Harts valley. This depression is somewhere about two miles in width, and is bounded on either side by ridges of dolomite.

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At Brussels Siding, a well shows black carbonaceous shales, very thinly bedded, while a boring beside it penetrated 165 feet of light and dark shales with bands of clay, followed by boulder-clay down to a depth of 191 feet, without the bed rock being reached. As the sides of the valley rise to a height of at least 150 feet above the plain, it is clear that at one time there must have been material filling up the valley to the depth of over 340 feet.

Further down the valley, on Zamenkomst, there are exposures of shale, while on Lange Rand, about a mile and a half south of De Beers' Halt, there are large ballast pits in horizontally-bedded black shales and nodular-weathering blue-black mudstone, containing fragments of plant remains.

These shales are traversed by a sill of Karroo dolerite, having a north-easterly trend. Along the hillside to the north-east, about a quarter of a mile from the railway, shales are exposed in a well within 12 feet of a cliff of dolomite, and it is clear that, as no fault is present, the shales abut undisturbed against a steep face of older rock.

Along this junction, water charged with calcareous matter, probably from the dolomite, has risen, and the hillside for a distance of half a mile is covered by a thick sheet of calcareous tufa and breccia, enclosing fragments of sandstone, quartzite, dolomite, amygdaloid, etc.

At De Beers' Halt there is a small area of boulder-clay, portions of which are much harder than usual.

It is clear that many of the natural features of the ancient pre-Dwyka land-surface are reproduced in but slightly modified form at the present day.

The boulder-clay is usually found in hollows and depressions, which were formerly glaciated rock-basins, *e.g.*, at Vryburg and O'Reilly's Pan, and several of the courses of the pre-Dwyka drainage system coincide with the present river valleys.

Thus shale and boulder-clay fill in the Dry Harts valley as far northward as Gamabot; the small patch in the midst of the alluvial plain on Weltevreden indicates that the ancient channel probably extended in this direction.

In the same way, the tributary rising on Borthwick flows over a wide area of shales and boulder clay at Van Vreda Dwaling, but, in the narrow poort a couple of miles east of Brussels Siding, a small patch of the latter is visible right at the foot of the dolomite ridge.

Probably the stream draining the flat on the Transvaal border and flowing past Dry Harts Siding also marks the position of an ancient valley.

The patches of boulder-clay on the plateau close to Tiger Kloof indicate that large areas of the Dwyka formation have only recently been stripped off the surface of the dolomite.

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The relation of the shales to the boulder clay is a very intimate one; they overlie the latter, but in a number of places they evidently fill up deep hollows in it, and they may therefore occur on the low ground, while the ridges round about are composed of the boulder deposit. In some places layers of shale occur in the midst of the boulder-clay.

Everything points to the shale being an integral portion of the Dwyka formation.

IX. Intrusive Rocks.

Though of varied types, the intrusions are remarkably few in number.

Hornblende Schist.—A rather wide outcrop occurs on the Piring Spruit, a tributary of the Molopo. The least altered variety is a dark-green rock, with hornblende prisms, visible to the unaided eye, and it occurs on either side of a belt of magnetic quartzites. There is no direct evidence to show whether it is intrusive in the latter or not.

In thin section (1432) the hornblende is seen to be a pale variety in large prisms; the groundmass consists of hornblende needles, abundant prisms of zoisite, water-clear felspar (possibly also quartz), sphene, and rutile.

The freshness and nature of the minerals indicate that the rock has probably been derived by metamorphism from a diabase, and that it has been completely re-crystallised.

This variety passes into a schistose rock, and with it is a small mass of sheared quartz-porphyry.

The intrusion can be traced up along the Molopo River for about a mile, and we then find for a distance of about 200 yards alternations of granitic-gneiss and hornblende-schist.

At the contacts with the granite the intrusion is always very fine-grained and schistose, but a little distance away from them the rock is invariably coarser grained and more massive.

The direction of the foliation agrees with that of the gneiss, and strikes in a north-westerly direction. The intrusion probably took place after the gneiss had partly received its foliated structure, but before the forces that produced the foliation had ceased. It is thus probably older than the magnetic quartzites.

Serpentine.—On the farm Regen Vlakte, west of Setlagoli, is a small outcrop of dark brownish-grey serpentine, at a point about three-quarters of a mile distant from the homestead.

The relation to the surrounding rock (granite) is not seen, but the serpentine is probably intrusive.

A thin section (1409) shows colourless serpentine, containing an abundance of chrysotile and flakes of iron ore; the cracks are also marked out by ferruginous material.

Other portions of the rock contain a certain amount of talc.

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Diabase.—A few dykes of pre-Karroo diabase occur; from their comparative freshness, they are probably later in age than the diabase lavas of the Ventersdorp series.

A thin section (1412) of an intrusion ramifying through the granite on the farm Never Set, in the Maretsani valley, shows a fine-grained rock, with elongated prisms of greenish-brown augite, partly converted into diallage. The groundmass consists of almost fresh felspar, a large amount of quartz, and a little epidote and iron ores.

A thin section (1434) from a dyke crossing the Molopo River just above its junction with the Madibi Spruit, has the following features:—Brownish augite, still fairly fresh, in long prisms; plagioclase felspars, crowded with patches and granules of augite and leucoxene; some quartz and chlorite.

Karroo Dolerites.—Several dykes occur, always recognisable by their freshness. In three of these their age is proved by the fact that they are intrusive in the Dwyka formation. The northernmost dyke noted was one crossing the Molopo River at a point about eight miles west of Mafeking.

In the few sections available, the ophitic structure is not well developed. Augite is partly or wholly altered to diallage, and sometimes to yellow-brown serpentine. A marked feature is the occurrence of patches of micropegmatite.

X. Superficial Deposits.

The underlying rocks are always more or less hidden by superficial deposits, of which the most widely distributed is sand.

(1) *Sand.*—This is usually coarse in character, and of a light yellowish-red or pinkish tint. In a few spots, notably north of the Maretsani River, towards the area entitled "First Railway Grant," the colour is very pale yellow or whitish. Apparently the sand is derived principally from the disintegration of the granite and gneiss of the district, and though it occasionally covers up other formations, it is never found overlying large areas occupied by diabase and dolomite.

Generally it may be taken that the depth of red sand increases as one proceeds northwards, so that the granite and gneiss is hardly ever exposed in that direction, except in river valleys or in wells, while only now and then do the more resistant rocks, such as the magnetic quartzites of the Kraaipan formation, project through it. For example, in the valleys stretching northwards from the watershed at Ennesdeel, Langewerk, etc., there are absolutely no exposures of rock, and the same is the case on the wide flats to the south-west of Pitsani.

On account of the depth of loose sand, it is sometimes impossible to sink wells without supporting their sides by means of timber or metal cribs; examples of such wells are found at Tlakgaming, on the road to Morokwen.

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(2) *Gravels.*—On the north side of the town of Vryburg there are gravels resting upon the soft Dwyka boulder-clay; close to the cemetery, where the material is being excavated, they form a layer from two to three feet in thickness. The pebbles consist chiefly of water-worn brown-weathered quartzites, probably derived from the Black Reef series, and agates from the amygdaloids, set in a matrix of small grains of quartzite, quartz, agate, etc. A few diamonds have been found in this deposit. On the flats to the north, and again to the east and south, patches of these gravels are found.

On the right bank of the Maretsani River, between Buck Reef and Harding, there are thick layers of gravels, fully 100 feet above the present bed of the river. The pebbles consist principally of ferruginous chert, magnetic slate, and agate.

Between Mafeking and Kliparani there is a flat-topped ridge, on which the trigonometrical beacon K. 14 is placed, and which is capped with gravels. The pebbles, which are principally of quartz and ferruginous chert, form a thick layer, and strew the hillsides for quite a distance from the crest of the ridge—right down almost to the bed of the Methlonyane Spruit.

The height of this gravel-covered ridge is fully 200 feet above the present bed of the Molopo, and it is evident that since these gravels were deposited, there has been considerable erosion in this part of South Africa.

(3) *Calcareous Tufa.*—This covers a large area, especially in the dolomite region, and to a lesser degree in that occupied by diabase and amygdaloid. It has evidently been produced by the rising through capillary action, and the subsequent evaporation, of water charged with carbonates derived from the underlying rock.

West of Mafeking, along the Molopo River, and to the north in the valley of the Mogasani River, there are large areas of granite and gneiss covered with tufa. It is most probable that the deposit has been laid down from water highly charged with the carbonates derived from the great dolomite area in which both of these rivers rise.

The calcareous tufa is usually very pure, often indeed containing but an insignificant amount of quartz, in the form of minute grains.

At Kraaipan there is a deposit of carbonate of lime, in the form of a finely-divided white powder.

These calcareous deposits often pass into breccias through the cementing together of pebbles of agate, quartz, etc. The tufa frequently contains shells of *Pupa* and *Succinea.*

In many places the rock is so firm that it can be used as a building stone, and has the great advantage that, although soft when quarried, it rapidly hardens on exposure to the air.

(4) *Pan Deposits.*—Calcareous tufa often surrounds and forms the bottoms of pans, especially of those situated upon the dolo-

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mite. It is more common, however, to find the pan filled in with a black soil, a mud in the summer time, but when the pan is dry, a loose friable powdery earth, which shrinks and is traversed by wide and deep cracks.

Towards the edge of the pan are commonly small pebbles, chiefly agates from the amygdaloids, while not uncommonly evidences of prehistoric man appear, in the shape of rudely-chipped implements.

Sometimes, but rarely, a quartzite is found forming the floor of a pan; a good example is met with on the farm Water Pan, north-west of Vryburg. A section afforded by a well is as follows: Red sand, calcareous tufa containing shells of mollusca, a thin layer of pebbles, hard green quartzite, and decomposed friable greenish granite. The quartzite shows grains of quartz, set in a fine quartzose and chalcedonic matrix. There are numerous little drusy cavities, either lined with chalcedony and agate, or into which crystals of quartz project. The green colour has evidently been produced by the ferro-magnesian minerals of the decomposed granite.

This quartzite, from its character and mode of occurrence, evidently corresponds to certain varieties of "Pan-sandstone" obtained by Dr. Passarge† from the Northern Kalahari.

XI. Pans.

Pans are very numerous throughout this area, and vary in size from a few yards up to nearly a mile in diameter; as examples of the last, we have O'Reilly's Pan to the north-west of Vryburg, and the Saltpan (Groot Chwaing) due north of that town.

The material found in these pans has been briefly noted above, but the two large pans require special mention on account of their unique character and the light they shed upon the mode of formation of pans in general.

(1) *O'Reilly's Pan* is a vast depression, surrounded by ridges of Black Reef quartzite or Dwyka boulder-clay. The diameter of the area of erosion is about two miles, while the actual pan itself is slightly oval, with a length of about two-thirds of a mile. The outlet of the pan is on the south-west side, at a level of about 40 or 50 feet above the pan-bottom. The ground on the north and south rises to a height of about 150 feet above the pan, but on the east this is greatly exceeded, owing to the quartz-porphyry ridge of O'Reilly's Fontein and Schat Kist.

The soft Dwyka boulder-clay is the formation in which the pan is excavated; on the west side, and again on the east, there are rounded and smoothed areas of quartzite projecting through the glacial rock. In a few places faintly striated exposures

† E. Kalkowsky. Die Verkieselung der Gesteine in der Nördlichen Kalahari. Mitth. K. Miner. Geol. Museum, Dresden, 1901.

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are found, and it is clear that the outcrops of quartzite are glaciated surfaces. The pan apparently marks the site of an old glaciated rock-basin, and the hollow has been produced by the erosion of the soft boulder-clay.

The bottom of the pan is covered with a friable blackish-grey soil, and a thick mantle of sand of a similar colour forms ridges on the south and south-east side of the pan, obscuring the underlying formations.

The direction of the prevailing wind is from the north or north-west, and it is thus seen that the excavation of the pan has been effected principally by the wind, aided by the disintegrating action of the water, which during nearly half the year covers the pan bottom. The calcareous matter which is blown up with the sand, and which often coats the sand-grains, is the source of the cementing material by which the banks of blown sand are often consolidated.

(2) *The Saltpan (Groot Chwaing)* is a large and irregularly-shaped pan, about three-quarters of a mile across, and but slightly depressed below the general surface of the country.

On the west and south-west runs a ridge of ferruginous cherty rock, while the pan itself is located on the flagstones at the base of Zoetlief Beds (see p. 236). These flags crop out all round the edge of the pan, while irregular ridges of the same break the continuity of the pan-floor.

Curiously enough, an abundance of beautifully fresh water is obtained all round the pan; in fact, wells have been put down on the flat of the pan, a few yards from its edge. Yet everywhere within the pan itself there is a strong supply of brine, which is found at depths of a few feet, even at the end of the dry season. The brine cannot have been derived by leaching from the surrounding country, and must therefore come up along channels and fissures from the underlying rock. In all, the brine-trenches flagstones are exposed, but the granite must exist below them at no great depth.

The temperature of the brine is, I am told, always slightly higher than that of the fresh water in the surrounding wells, and supports the view of the deep-seated origin of the saline material. The brine is very pure, and is not accompanied by gypsum or sodic carbonate.

On the south and south-west sides of the pan there is a ridge covered with blown sand. The floor of the pan is formed of a very light powdery soil, which even a slight breeze is able to carry away.

The brine solution attacks the flagstones, and they become covered with peculiar pittings and hollows like those so well seen in the Malmesbury slates on the sea-shore at Green Point. The flags being highly micaceous and fissile, break up readily, and in this way, by disintegration and wind erosion, the pan is gradually being deepened.

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The sand on the hills south of the pan is charged with salt; this is gradually dissolved out by rain-water, and the saline material returned to the pan. On the east side, there is a considerable extent and thickness of calcareous tufa.

The supply of salt is apparently inexhaustible, and from three to four thousand bags have been removed annually for a number of years.

(3) *Other Pans.*—There are innumerable other pans, but none are much over a quarter of a mile in diameter.

The origin of these is generally uncertain, but, as in most of them the bottoms are covered with friable black earth, it is probable that wind action has played an important role in their formation.

But it is quite as probable that wild animals are responsible for the removal of a great deal of material from such pans, a view propounded both by Mr. Alison* and Dr. Passarge.† In the case of the Saltpan, the influence of wild animals must have been extremely small, while the action of wind is clearly marked.

The evidence in this area shows that it is impossible to propound a single theory to account for the origin and formation of every pan.

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* M. S. Alison, On the Origin and Formation of Pans. Trans. Geol. Soc., S. A., Vol. IV., p. 159, 1899.

† S. Passarge. Die Kalahari, Vol. I., chapter 17, pp. 304-317, Berlin, 1904.

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GEOLOGICAL SURVEY

OF THE

DIVISIONS OF TULBAGH, CERES AND WORCESTER.

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GEOLOGICAL SURVEY OF THE DIVISIONS OF TULBAGH, CERES, AND WORCESTER.

By Ernest H. L. Schwarz.

In the First Annual Report of the Geological Commission, published in Cape Town in 1897, there appeared a "Summary of the Work done in the Tulbagh Area and Worcester District"; it was an abstract of a full Report on those districts, which the then Director of the Survey, Dr. G. S. Corstorphine, held over pending confirmation of the points brought together in it; and since then, so continuous has been the exploration of the Colony, and the time for working up results has been so short, that no occasion has offered in which to revise this Report. The present work is an account of the Geology of the districts surveyed by me in 1896, re-written entirely, and considered in the light of the knowledge that we have since acquired.

It must be remembered that when the survey was started, no systematic work had been done in the south-west of the Colony. We had A. G. Bain's map and description, but his results had been questioned by Dunn, Cohen, Moulle, Rubidge, and others, and no one knew which author to follow. It was not in matters of detail that these authors disagreed, but the fundamental division of the rock-systems was in dispute. There are two slate formations—the Malmesbury and Bokkeveld series—and two sandstone formations—the Table Mountain and Witteberg series; were these the same or were they different? That was the question that no one could answer, and no one seemed to be able to find criteria by which to settle the point. Even Dunn, who spent a great deal of time in the field, was unable to distinguish between Bokkeveld and Malmesbury slates, but mapped large areas of the former beds about Caledon as belonging to the latter series, while such a keen geologist as the late Prof. Cohen maintained that the Witteberg sandstones were identical with the Table Mountain sandstone. The whole of the geology had, therefore, to be considered from the beginning. Luckily the district was one in which a final solution of the difficulties could be found, and the conclusions arrived at in this district have been accepted and found correct over the rest of the

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Colony where the same systems occur. Structural points of very great value were also revealed, as well as one of very great economical importance. Put synoptically, the results were:—

1. Establishment of the succession of the rock-systems.
2. Critical description of the beds by which they could be recognised elsewhere.
3. The recognition of the S-shaped bend, a syncline and anticline, as underlying the structure of the mountain ranges.
4. The discovery of the Worcester-Swellendam fault, with a drop of 10,000 feet on the south side.
5. The explanation of the presence of Dwyka and Ecca beds to the south of the folded mountain ranges.
6. The discovery of many new species of fossils.
7. The confirmation of the glacial origin of the Dwyka conglomerate.

The point of economic interest is worth emphasising, as so many look to geological survey work as having no direct value. Dunn had stated that the Karroo beds lay in a basin, and that at their base there was a bed of carbonaceous shales. He had traced this bed outcropping along the Orange River, down along the west side of the Karroo, and then eastwards north of the Zwartberg mountains. He had argued that, though the rock at the outcrop was poor in carbonaceous matter, nevertheless, as the rock had been deposited in a basin, it was reasonable to suppose that there had been an accumulation of organic matter in the deeper parts of the basin, and that, in consequence, there would be vast deposits of coal underlying the central Karroo. The discovery of Ecca and Dwyka beds south of the folded mountains, containing a carbonaceous bed identical in composition with that of the beds north of the mountains, proved that the southern rim of the Karroo basin, when it was originally formed, lay far to the south of where Dunn had supposed it to lie, and that the outcrop along the Zwartberg Mountains, instead of representing the impoverished external rim of the coal beds, was actually the strata in the centre of the basin brought to the surface by the folding that produced the mountains; and since they were just as poor in the centre as in the rim, it was not reasonable to suppose that they would increase in carbon content in any other part.

I divided my work at the time into two parts; first, I studied the rock systems in their normal condition north of the great Worcester-Swellendam fault, and then I turned to the disturbed area south of the fault, and tried to understand the geology here. The district, however, was not one in which a worker could be given a hundred miles or so to work out in detail, unless there was an adequate description of the leading lines to commence with.

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Commencing the description from the west, we find a range of hills, made of Table Mountain sandstone, extending northwards from the Drakenstein mass. They are known as the Limiet Berg, Eland's Kloof Mountains, Vogel Vley Mountains, Roode Zand Mountains, and the Winter Hoek Mountains. At the southern end, opposite Wellington, the area of sandstone is ten miles wide, but this narrows considerably northwards. The railway line is carried on the western side of the mountains, and strikes through them at their narrowest part by Porterville Road; it then doubles all the way back along their eastern side as far as Worcester, when it doubles back again, and strikes through the second barrier of mountains through the poort of the Hex River.

Taking the first range, we find the sandstone of the Table Mountain series resting on an embankment, as it were, of slates. It is at its simplest at the narrow portion—the Roode Zand Mountains, where it is merely a flat, or slightly undulated mass of strata, crushed, however, longitudinally, so that, seen both in section in the New Kloof and along the length of the range, we see slight puckerings and foldings. Where the old road used to go over the mountains, before the Kloof was made practicable, there is a somewhat complex arrangement of faults, the net result of which is to let in a tongue of slate between the sandstone krantzes; as slate weathers so much more readily than sandstone, the slip of argillaceous beds enabled a road to be cut more easily than could have been done elsewhere.

I am not sure of my geology about here; there must be many more faults than those which are plainly visible, and this is, in effect, what is to be seen everywhere in hills made of Table Mountain sandstone in this region. Where there is a great mass of the rock, the similarity of the beds throughout the whole system makes it impossible to detect slight faults, unless very careful search is made; but here, where the beds have been reduced to little more than a remnant, one sees the faults more plainly.

As we go south from the New Kloof, the area of the sandstone widens, and gradually the S-shaped fold begins to develop itself. At the New Kloof we have the remnant of the syncline; further south the anticline is added, and we have the two great kloofs, Bain's Kloof and Slang Hoek, cut more or less in the axes, the one of the syncline, the other of the anticline. The edge of the latter where it should dip under Bokkeveld beds is hidden by enormous accumulations of boulders, formed of Table Mountain quartzite (Fig. 1), and the nearest rock that one can see is the Malmesbury beds, so that there is evidently a fault here. We shall see presently that this fault increases rapidly in intensity, and at Worcester lets down rocks on the south side quite 10,000 feet. Beyond Slang Hoek there is a great knot of

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mountains of Table Mountain sandstone, and formed by the schaarung, or meeting of the north-south and east-west systems of rock folds.

FIG. 1.—Eastern end of Bain's Kloof, showing the nature of the Table Mountain sandstone boundary, and the hiding of all rocks in the valley by deposits of the Breede River.

To the north of New Kloof, the sandstone area also enlarges and joins up with the mass in the Winterhoek, which is part of the second range of mountains. In this way there is formed in the Tulbagh valley a cul-de-sac of Malmesbury beds, surrounded by high mountains of Table Mountain sandstone.

THE MALMESBURY BEDS.

The Malmesbury beds in the Tulbagh valley strike north and south, with variations up to 10° either side; while abnormal dips at right angles to the general strike are not uncommon, the dip is usually to the west from 60° to 80°.

The rocks are much sheared, silvery-grey phyllites, with bedding-planes apparently the same as the shear planes; intense crumpling in places, and occasionally sandy beds and green mudstones. On the Roode Zand Mountains' side there are many quartz veins running parallel to the range. On the Witzenberg side the junction of the Malmesbury beds with the Table Mountain sandstone is very remarkable, and at one time I thought there was an actual conformity. At Schalken Bosch Kloof, for instance, the Malmesbury slates distinctly dip under the sandstone beds at precisely the same angle as the latter strata make with the horizon, and to add to the confusion, the base of the younger series is made up of purple shaley and gritty beds, with quartzite interbedded. The whole section, to anyone seeing

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this section alone, would lead him to describe an actual passage from the shaley Malmesbury beds to the sandstones of the Table Mountain series, through a zone in which both varieties alternate. A little to the north, at Tiger Kloof, the unconformity is well exposed, and no doubt can remain as to the true nature of the junction (Fig. 2).

Following the Malmesbury beds south, there is nothing very remarkable to notice till one passes the entrance to Mitchell's Pass, and the Table Mountain sandstone strikes away to the east. At Eendracht there is a great bed of white quartzite in the slates, accompanied by a thinner band a little way away. Nearing Worcester, there are other varieties, which made me think of

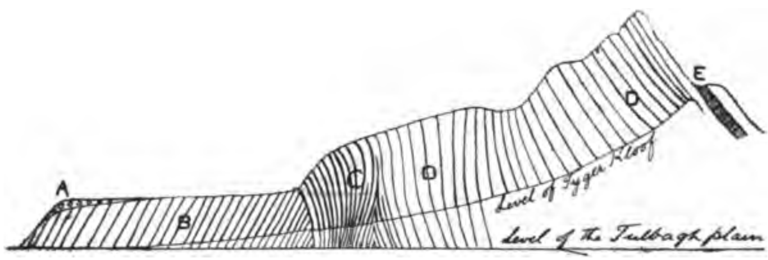

FIG. 2.—Section of the Tulbagh side of the Witzenbergen, showing the junction of the Malmesbury and Table Mountain beds. A, covering of gravel on an old river terrace; B, normal Malmesbury clay-slates; C, grits, quartzites and purple slates with ottrelite; D, normal sandstones of the Table Mountain series; E, upper shale band.

the Barberton beds in the Transvaal. North of Worcester there is a body of white crystalline limestone in the cleaved slates, and many veins of crushed granite. There is probably a mass of granite underlying this portion, for further to the east there are two granite bosses similarly situated; it is from this that I think the dykes have come, and to it is due the development of curious minerals, ottrelite for one, that one finds in the dense, hard, blue-black slates of Brewel's Kloof. Only a short way to the east, the railway cuts through the beds, and all trace of contact metamorphic action has ceased, and we find normal, silvery-grey phyllites, intensely sheared. At Ganze Kraal, however, on the far side of the railway, the ottrelite rocks come in again just under the sandstone.

Still following the Malmesbury beds along the edge of the Table Mountain sandstone, we find that they occupy a narrow strip about a mile wide, and form slatey foot-hills to the rugged mountains. On the south side they are cut off by the great Worcester-Swellendam fault, which I will describe later on.

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The Table Mountain Beds.

The Table Mountain sandstone of the inner range of mountains is exposed better than anywhere else in the Colony. From the north come the lines of the Witzenbergen and Schurftenbergen, prolongations of the Cederbergen, and from the east come the Langebergen. These two lines of mountains meet in a great knot with many puckerings on a gigantic scale, and a sunken area in the embrace of the bend, called the Warm Bokkeveld. The outer range of mountain chains meet similarly, and form a true "schaarung" or streaming of the structural lines; the knot-form of the junction of the inner ranges is perhaps due to the great Worcester-Swellendam fault. The outer ranges do not come within the scope of the present description.

Fig. 3.—The Witzenbergen from the top of the Schurftebergen, showing the steeply inclined Table Mountain sandstone near the head of the Witzenberg Valley, and the shale band at the top of that rock series.

The Witzenbergen and Schurftenbergen are formed respectively by the outer limb of the syncline and the anticline of the S-shaped fold, which, I have already said, forms the basis of all the mountain chains in the folded region. There is no mistaking the fold in this double range, for the syncline for part of its extent bears an outlier of Bokkeveld beds which contain typical fossils. Near Mitchell's Pass, the Bokkeveld beds pinch out, then, to still make clear the S-shaped fold, the Table Mountain series here contains a very well-marked Shale Band (fig. 3),

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which, folded in the particular way, leaves no doubt of the structural formation of the mountains. Elsewhere where we get Table Mountain sandstone intensely folded, so that the limbs of the folds all dip the same way, it is often difficult to distinguish individual bends, as there is no differentiation of the strata, all are sandy; in other words, the Shale Band is not a constant feature of the series.

In the knot of mountains the strata are lying much flatter, and it is difficult to make out the folding. Near the top of Mitchell's Pass the Shale Band is well exposed in the road-cutting, but, unfortunately, here, in the most accessible locality, it is not typically developed, the shales being replaced by argillaceous sandy beds; it is only when one remembers that the

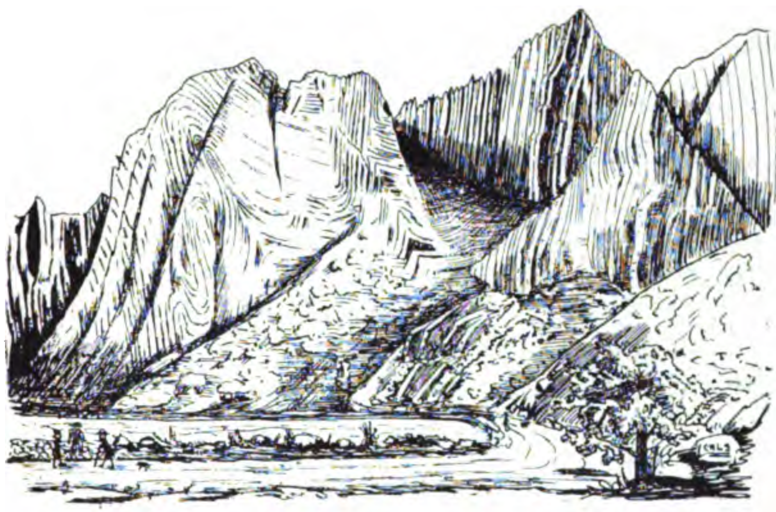

FIG. 4.—Kogman's Kloof, near the entrance of Keur Kloof. Perpendicular and crushed Table Mountain sandstone.

bulk of the Table Mountain series contains no clayey material that the significance of the clayey bed in the road-cutting can be understood. The little argillaceous matter, however, is sufficient to make the soil resulting from its decomposition richer than that derived from the ordinary Table Mountain sandstone, hence the bushes always stand thicker in this belt of rock, and produce a dark line across the mountains.

East of the knot, the Hex River Mountains strike away to the north-east, to culminate in the fine peak Matroosberg. The range is formed by the anticline of the S-shaped fold; the syncline includes the Bokkeveld valley of the Hex River. The outer limb of the syncline strikes a little south of east, and forms the Langebergen, but it is itself broken up by subsidiary folds, which produce hill-ranges of their own. The enormous amount

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of shearing and internal movement which these ranges have undergone is splendidly brought out in the section along Kogman's Kloof, from Ashton to Montagu, a sketch of a part of which I give (fig. 4).. We are, however, not much concerned with the Langebergen in this report.

The Table Mountain sandstone surrounds the Warm Bokkeveld on three sides, the fourth being occupied by hills of sandstone, but of a far younger age, namely, the Gydow or Waagenboom's Mountains, made of Witteberg beds. Many have looked upon the Warm Bokkeveld merely as a quadrangular outlier let down by folds. On the west there are the Schurftenbergen, running in a straight line northwards and exhibiting steep dip-faces of rock. There is an outer series of crests, behind which are the softer beds of the Shale Band, and behind this again are the hills made of the bulk of the rock-series. At places the shale has peeled off the sandstone, leaving enormous slabs of bare rock. This is best seen from Prince Alfred's Hamlets.

If we mount the step from the Warm to the Cold Bokkevelds, and follow the Schurftebergen, we find the outer ridge of hill-crests sinking as it were into the ground, and the Shale Band increasing very greatly in thickness; this is not really the case, for the width of the band is doubled by a sharp anticline (fig. 5). Very fine sections of the Shale Band can be seen just behind the outer ridge of jagged, pinnacled kopjes. The rocks are finely laminated, purple and blue shales, often sufficiently close-grained and consolidated to afford large slabs of only an eighth of an inch in thickness; the rock parts along the bedding planes, but is not sufficiently hard to be used as a roofing slate. I searched these beds most carefully for traces of graptolites or moluscan remains, but unsuccessfully. If we are ever to obtain fossils from the Table Mountain series it is in these beds that they will be found.

The southern border of the Warm Bokkeveld is formed by the great knot of the Hex River Mountains; the inner border of the Table Mountain sandstone is obscured by the river deposits and swamps along the stream beds, but we can plainly see the sandstone dipping under the plain at the foot of the hills. At Ezel Fontein there is a fine little anticlinal ridge projecting at right angles to the mountains, the nose, as it were, cut off by a transverse fault. At Welvaart much the same thing occurs, only the fault, which is parallel to the Ezel Fontein one, cuts off the greater portion of the anticline.

Beyond this point the Hex River Mountains break up into three divergent ridges, each formed of an anticline, and which divide the Warm Bokkeveld into three compartments.

The first forms the ridge over which the old Kimberley road goes, and the kloof which is utilised is called Hottentot's Kloof; it was the last mountain pass before striking into the Karroo

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FIG. 5.—The Cold Bokkeveld, looking across the slate valley or plain, from the Witteberg hills, on the east of the Gydow Pass. The Schurftebergen are seen with an edge of jagged quartzite kopjes; behind this there is a wide belt of slates belonging to the so-called Upper Shale Band. In the right centre the Shale Band is seen repeated by an anticline. On the right, the strike of the beds is suddenly changed; this is on the line of the fault which lets down the Dwyka beds against the Witteberg hills to the east. The farm houses are: on the left, Eland's Fontein; on the right, Molen River.

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on the long, weary journey to the North. The ridge is not made of Table Mountain sandstone on the surface, and were it not for a transverse buckling, which causes anticlines lying across the general direction of the main subsidiary fold to push the sandstone through the Bokkeveld slates, there would be no sandstone at all to be seen.

The tertiary folds, as we can term them—the primary one being the backbone of the Hex River Mountains, the secondary one the buried anticline which carries these tertiary ones as transverse bucklings—are of supreme importance in the study of South African geology. To see the ends of the larger one either on the west, at Leeuwen Fontein, or on the east, at Uitkomst, and to see the sandstone plunging on all sides below the slates, and the Bokkeveld slates, with their tiers of sandstone krantzes, dipping away from the sandstone and conformably to it, making a fine amphitheatre, is to set all doubts at rest about the succession of the series.

There is another interesting point brought out in connection with these tertiary folds. We can often see the actual junction of the Table Mountain sandstone and the slates, and we find that there is frequently a space which is filled in with quartz crystals up to six inches in length and a couple of inches in diameter. This is important in view of the fact that most of the springs in these districts come out in the junction of the Bokkeveld with the Table Mountain series. As we see a definite zone which is occupied with large quartz crystals evidently deposited from solution, the conclusion which we draw from it is that the actual junction of the two systems is the water-bearing zone, and in deep boring this is the horizon that we should strive to strike.

The middle projection of the Hex River Mountains is like a gigantic garden trowel, with the convex side upwards, and stuck slanting into the ground. The culminating peak, Matroosberg, would be where the haft of the trowel joins on to the blade.

The third or easternmost prong of the mountain fork is a long thin anticline, cut off on the north by a vertical fault. On the south side the ground of the plain at the foot of the hills is on a level with the Cold Bokkeveld, but in the north it is on a level with the Warm Bokkeveld; the streams running off the northern face have, therefore, had a far greater fall than those that come off the south face, and the consequence is that one of them has eaten back right through the range and has tapped the drainage-supply of the southern high-level flats. The stream cuts across the fault on the north side, and if one walks along the stream bed from Karbonaatjes Kraal on the south side, one suddenly finds the little stream dashing down a vertical wall of some 600 feet in height (fig. 6). The place where the water falls is not the actual fault-face, but is in a recess cut back some hundred yards from the fault, and no more wonderful

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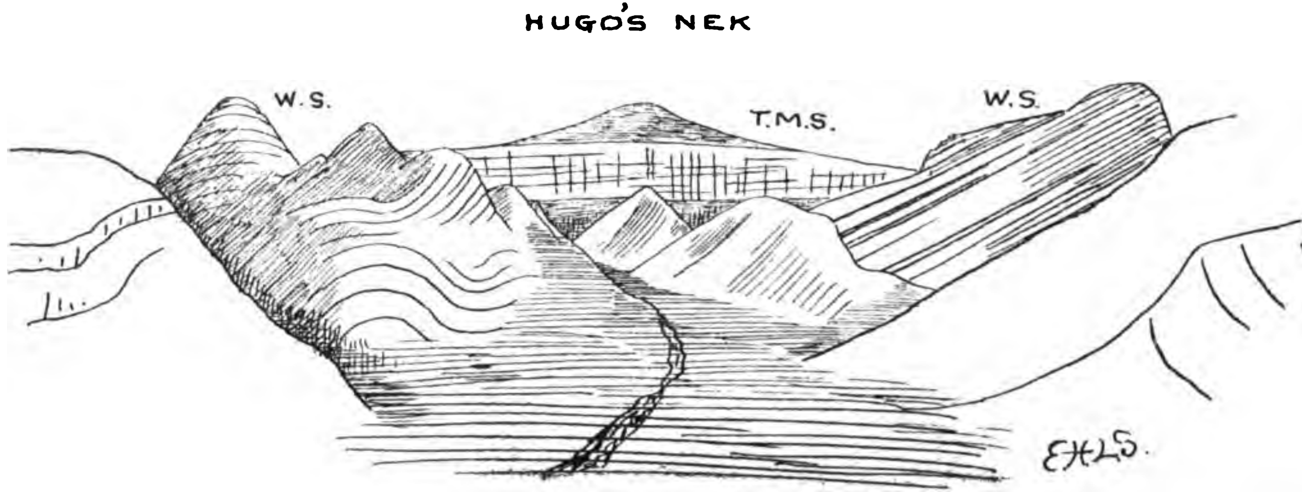

Fig. 6.—Hugo's Nek near Verkerde Vley, showing the fault-face of the Table Mountain sandstone, with inclined beds of Witteberg quartzite (W.S.) resting against it.

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sight is to be seen in the neighbourhood, which certainly does not lack in grand and beautiful scenery, than in this great recess, and where one can see the sandstone walls towering vertically upwards all round one. The place is called the Kaaiman's Gat.[1]

Turning now to the outer limb of the primary syncline, we find it split also into three portions by secondary and tertiary folds. The most northern of them bounds the Hex River on the south, and the hill-range is called the Kwadouw Mountains. There is a syncline passing diagonally across it which lets down Bokkeveld beds between the nearer and further portion of the secondary anticline, so that the sandstone ridge of the Kwadouw is truncated; the portion beyond the diagonal syncline does not come fully to the surface of the ground, but a series of small anticlinal ridges of sandstone project above the slates of the Bokkeveld series. The middle secondary fold is a narrow anticline that runs to the north of Montagu, and shuts in between itself and the Langebergen, the third of the secondary folds, a remarkable area, known as the Coo and the Kasey. The Langebergen continue for some distance as a single limb of the syncline, but soon broaden out, by smaller bucklings and crushings, and further to the east, increase by the inclusion of a number of isoclinal folds.

The Bokkeveld Beds.

The Bokkeveld beds occur in the synclines of the Table Mountain sandstone, and occupy the following areas:—The Witzenberg valley; the Cold Bokkeveld; the Warm Bokkeveld (three portions); the Baviaan's Berg valley; the Hex River valley; the Coo and the Kasey; and the Brand Vley valley south of Worcester.

The Witzenberg valley is, on the whole, a very narrow band of slates; the northern portion broadens out into a flat plain, but is cut off by a transverse fold, while on the south the slates run up into a narrow trough, and become pinched out. Fossils occur sparingly near the Table Mountain sandstone junction; I obtained on the farm Welgemeend a *Homalonotus* and some fine little *Chonetes setiger*, and a *Spirifer*.

In the Cold Bokkeveld there is very little of the Bokkeveld beds to be seen: the whole of the low-lying country is covered with sandy soil derived, on the one hand, from the hills of Table Mountain sandstone, and, on the other, from the escarpments of the Witteberg beds. The rivers, also, are low grade, being checked at their outflow by hard quartzite banks, so that much of the ground is swampy. At the Gydow Pass there is a drop

[1] Not to be confounded with a place of the same name and very similar in appearance, on the George coast.

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of about 900 feet down to the Warm Bokkeveld, caused by the accumulated effect of several monoclines, with downthrow to the south.

The Warm Bokkeveld has usually been ascribed to the action of running water which had become dammed up by the closure of Mitchell's Pass, and then, when the barrier broke, the water rushed away, leaving a hollow in the hills behind the obstruction. The primary cause of the Warm Bokkeveld, however, is that an area of soft slates has been let down by folding. Water action has played an important part in producing secondary features, for I can recognise a high-level plateau passing over Hottentot's Kloof and the Cold Bokkeveld, and traceable on the top of the Hex River Pass on the other side of the encircling mountains, which was produced by the rivers being checked, and levelling a plain by their meanderings; I can also recognise a

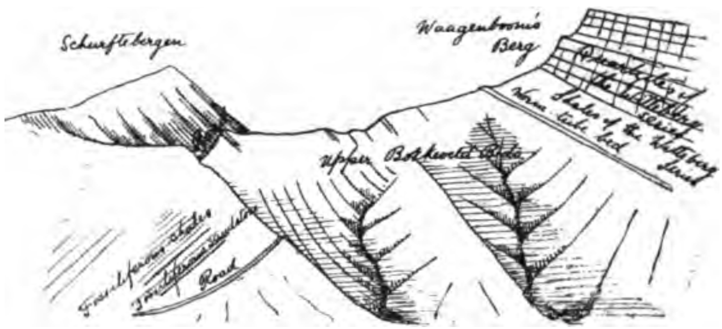

FIG. 7.—View of the Gydow Pass from the bottom, showing the quartzites of the Witteberg series apparently resting unconformably on the Bokkeveld Beds, thus affording grounds for the late Prof. Cohen's view that the Bokkeveld beds were the same as the Malmesbury beds, and the Witteberg quartzites as the Table Mountain quartzites. The reversal of the dip along the road is due to a small fold as explained in the text.

second plateau only a score of feet above the present level of the streams, which is represented by the gravel flats about Prince Alfred's Hamlets. The erosion of the valley has not been due to any stupendous rush of water, but to the slow eating out by normal river action, violent enough indeed when the winter rains set in, and the water rushes down the steep-graded rivulets, but not in the sense of a cataclasm due to the bursting of a high barrier; there has always been a barrier at the entrance to Mitchell's Pass, and it is still obstructing the streams, and it has at one time been eaten away by the rivers more slowly than the tributaries brought detritus, so that an alluvial plain has been formed behind it, but then subsequently the barrier was eroded more quickly, and the alluvial plain cut into by the rivers and removed, without a lake having formed.

A classical place for studying the Bokkeveld series is on the Gydow Pass. On the left as one goes up there is the Table Moun-

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tain sandstone dipping under the slates, and on the right there is the Witteberg beds capping them. The succession is, however, obscured by a monoclinal fold, which traverses the beds diagonally to the face of the escarpment up which the road winds, and this produces reversed dips and duplication of beds (fig. 7). The succession is, therefore, by no means clear. Gydow Pass has always been a prolific hunting place for fossils; near the middle there are some grey micaceous shales, from which large specimens of *Homalonotus herscheli* can be obtained, and a little higher up, to the right of the road, there is a bank of soft, grey-blue shale, stained yellow with iron ochre, full of *Leptocoelia flabellites.* From the same bed as the last I obtained many specimens of another characteristic North American Devonian fossil, *Vitulina pustulosa. Orthothetes sulivani, Spirifer orbignyi, Sp. antarcticus, Ambocoelia umbonata, Retzia adrieni, Centronella silveti, Cryptonella, Rensselaeria, Bellerophon (Bucaniella) trilobatus, Loxonema, Holopea baini, Tentaculites baini, Conularia quichua, Nuculites abbreviatus, N. africanus, Actinopteria eschwegei,* Modiomorpha baini, and Typhloniscus baini* were all obtained from a mass of material that I dug out in this same face, some of them new species and many new to South Africa.

Following the slopes of the hills below the krantzes of the Gydow mountain, I could obtain no fossils till I came to Hottentot's Kloof, where the Witteberg beds are set back rather sharply. On the level top of the pass there was at the time of my visit a roadside quarry, from which I obtained a large quantity of a peculiar, oyster-like Spirifer, named by Mr. F. R. C. Reed *Spirifer ceres. Ambocoelia umbonata* and *Centronella silveti* also occur in the same bed here.

In the kloof on the eastern side of the Pass some rare Lingulas were found, one resembling *L. densa.*

At Leeuwen Fontein, probably the same farm as Leo Hoek, mentioned by Sharpe, I was unsuccessful in obtaining any fossils, though Bain records from here *Grammysia corrugata, Nuculites ovatus, Palaeoneilo antiqua, Modiomorpha baini,* and *Anodontopsis rudis.* The farm lands are, geologically speaking, remarkably situated. A great rounded anticline of Table Mountain sandstone plunges beneath the slates, and the latter have been eaten away by the action of running water; encircling this bared mass of white sandstone there are three concentric rings of slates, each capped with hard sandstones, and between these hogs' backs and the sandstone lie the farm buildings and gardens. The sandstones I named the Fossiliferous, and the 1st and 2nd White Sandstones, as the first was a blue rock, weathering red, and often full of fossils, whereas the White Sandstones were so strikingly different. Subsequently it has been thought

* This has not been yet recorded from S. Africa; it is a South American form.

best to re-name these sandstone bands the 1st, 2nd, and 3rd Sandstones, without a qualifying adjective, but it is a little unfortunate, as the Fossiliferous sandstone is calcareous and easily obliterated by shearing, whereas the other sandstones are conspicuously plain in most sections.

To the south the farm Laken Vley adjoins Leeuwen Fontein; here on the south of the long Table Mountain sandstone anticline I obtained a bed almost entirely made up of casts of *Terebratula baini*. A fine tail of *Phacops caffer*, consisting of a black carbonaceous shell embedded in a white micaceous sandy shale, was found near the homestead; this last bed is probably the same as that on Gydow Pass, where the *Homalonotus herscheli* occur in a similar matrix, only that it is greyish instead of being bleached white.

Following the rim of the Warm Bokkeveld to the south there are few good hunting places for fossils; the ground is an elevated plateau, and it is not till one reaches Ezel Fontein, or, as it has once been called, Glen Etive, that one comes on suitable sections. There there is an escarpment somewhat like the Gydow Pass, only not quite so high, and the beds seem much darker, probably on account of the greater steepness of the escarpment and consequent less weathering that has gone on on the surface. The hills to the east of the homestead afforded a great quantity of Nuculites, the species *N. branneri*, *N. africanus*, *N. colonicus*, and *N. martialis*, all coming from here. *Grammysia*, probably *G. chemungensis*, and *Cardiomorpha campestris*, also occurred with a few remains of Trilobites. On the north of the homestead there is a field in which the clayey soil barely covers the yellow shales beneath; every year the plough brings up fresh lumps of rock from below, and in these there are numerous nodules about the size of a man's fist. On breaking these open some beautifully preserved fossils can be obtained; they are mostly casts of the heads and tails of *Homalonotus herscheli*, and what I believe to be another species, or perhaps the female form of the ordinary *H. herscheli*; lamellibranchs are well represented, large perfect casts of *Palaeoneilo rudis*, *P. antiqua*, *P. subantiqua*, and *P. fecunda*; *Bellerophons* and *Tentaculites* are often found in with the larger forms, but no brachiopods turned up. I believe the Fossiliferous sandstone divides the two fossiliferous beds on Ezel Fontein.

North of Ezel Fontein, along the road on Zwar Moed, there is a bed of blue-black sandstone, with a layer of large spirifers at the bottom. Between Ezel Fontein and the village there are a number of spots where fossils may be obtained. At Stink Fontein there is an outcrop of the Fossiliferous sandstone, with a layer of small indeterminate brachiopods in it, and near by in a hard black slate there are some small forms of life, such as *Tentaculites*, *Bellerophon*, and gastropods.

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Close to the village a farmer of the name of Wolvaart had dug a well in some soft greenish micaceous shales, from which a considerable number of fossils have been obtained. They consist of fine crinoids, *Phacops caffer*, *Orthothetes sulivani*, and small lamellibranchs.

In the second compartment of the Warm Bokkeveld, behind Hottentot's Kloof, there is a very fine collecting place on the farm Uitkomst. Starting from the high ground, there are two valleys running down to the farm along the edge of the Table Mountain sandstone ridges (fig. 8).

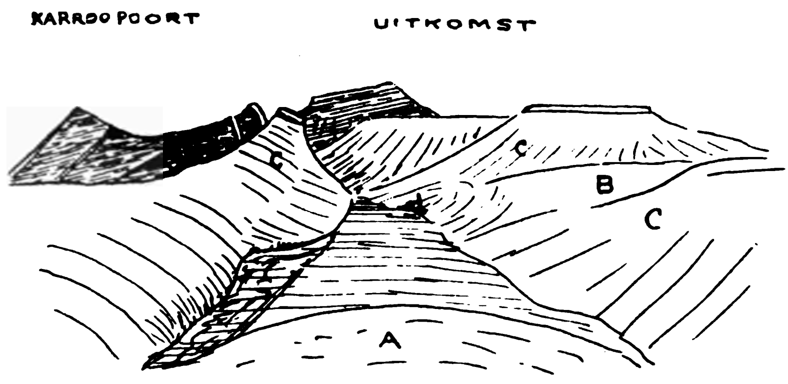

FIG. 8.—Looking towards Uitkomst from the Groen Fontein anticline of Table Mountain sandstone, A. B is the Laken Vley anticline of Table Mountain sandstone. C.C. are slates immediately above the Table Mountain sandstone. The hills in the distance to the left are made of Witteberg beds steeply folded; they were erroneously taken to be the eastern end of the Zwartberg Mountains, hence what we now know as the Witteberg beds were originally called Zwartberg beds.

That on the south afforded almost at the first trial a large nodule composed of yellow clayey material, in which I found on breaking it open a very large Trilobite, named by Mr. P. Lake *Homalonotus colossus*. With the quantity of material obtained at Ezel Fontein before me, I am not sure that the species is different from the ordinary *H. herscheli*; there seems to be nothing of specific value between the larger forms obtained from the nodules at the latter place and this monster from Uitkomst. The blue shales down this part of the kloof are sparingly fossiliferous, and I could only now and again come across an occasional *Leptocoelia flabellites*, *Retzia adrieni*, *Ambocoelia umbonata*, *Conularia undulata*, or *Phacops africanus*, but the isolated specimens were finely preserved. There is in places a thin layer of black harsh slate, stained with pyrites, which contains large quantities of casts of *Orthothetes sulivani*. In the northern valley the same beds occur, but contain very few fossils.

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At the homestead there are literally miles of walling built round the lands, with lumps taken from the bed of Fossiliferous sandstone which covers the hill to the north. Very fine casts of spirifers can be obtained from these walls, and in the rock *in situ*. I found places where the casts showed the internal spiral whorls. The common spirifer is *Sp. antarcticus*, but the allied *Sp. orbignyi* also occurs with *Chonetes coronatus* and joints of crinoid stems.

In the third compartment of the warm Bokkeveld, that which contains the lake or vley called Verkerde Vley, the valley is covered with an accumulation of sand owing to the erosion of the rivers being checked by the hills of Witteberg quartzite, so that the debris cannot be carried away. Under the slopes of Matroosberg, however, on Hartebeest Kraal, some nice Leptocoelias were found, with *Orthothetes sulivani* and *Chonetes falklandicus*.

The Hex River valley is a magnificent syncline, showing on the east side the hogs' backs, formed by tilted shales, capped with hard sandstones. The

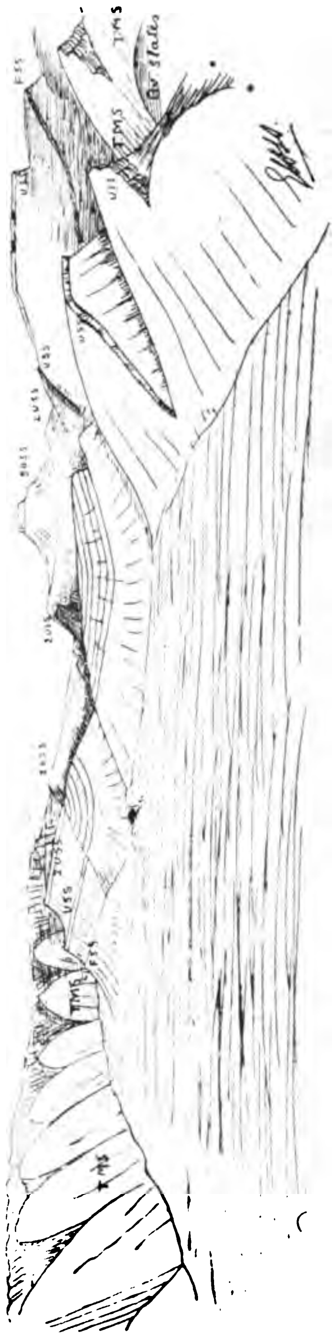

FIG. 9.—View of the Hex River Valley, looking east. In the centre is the Station, De Doorns on the low ground. Behind De Doorns is the August Rug. To the left there is the valley of the Hex River, while the railway turns up the kloof round August Rug. On the left of the picture there are the dip slopes of Table Mountain sandstone under Matroosberg, and on the right, the foot hills of the Quadow's Mountains. T.M.S., Table Mountain sandstone. F.S.S., Fossiliferous sandstone. U.S.S., First Upper or White sandstone. 2.U.S.S. Second Upper sandstone. 3.U.S.S., Third Upper sandstone; these last four sandstones belonging to the Bokkeveld series. Height of De Doorns above sea level, 1,566 feet; Triangle, on top of the plateau behind, is 3,196 feet.

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FIG. 10.—The entrance to the Hex River valley from the Worcester side. The peak on the left is Matroosberg; the farm house on the right, Ganze Kraal. The syncline seen in the next figure runs up on the left of the illustration.

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sketches appended (Figs. 9, 10, 11) will show the distribution of the beds better than a written description. The hill to the left of De Doorns has afforded since I was there many fine fossils, such as Phacops, Spirifers, and crinoids, but I did not in this first survey pay much attention to detail; it was in this valley, however, where I first realised that the Bokkeveld series is made up of a definite order of shales and sandstones, which are constant over large areas. The railway after leaving De Doorns climbs up the hills behind by a series of loops and turns, which exhibit the structure of these hills very finely. At Tunnel Siding Mr. Rogers and myself obtained some good lamellibranchs on a subsequent visit.

The valleys of the Coo and the Kasey stand in much the same relation as the Cold and the Warm Bokkevelds, the Kasey being the low ground near Montagu, and the Coo an elevated tract on a level with that at the top of the Hex River Pass; in fact, I regard the Cold Bokkeveld, the top of Hottentot's

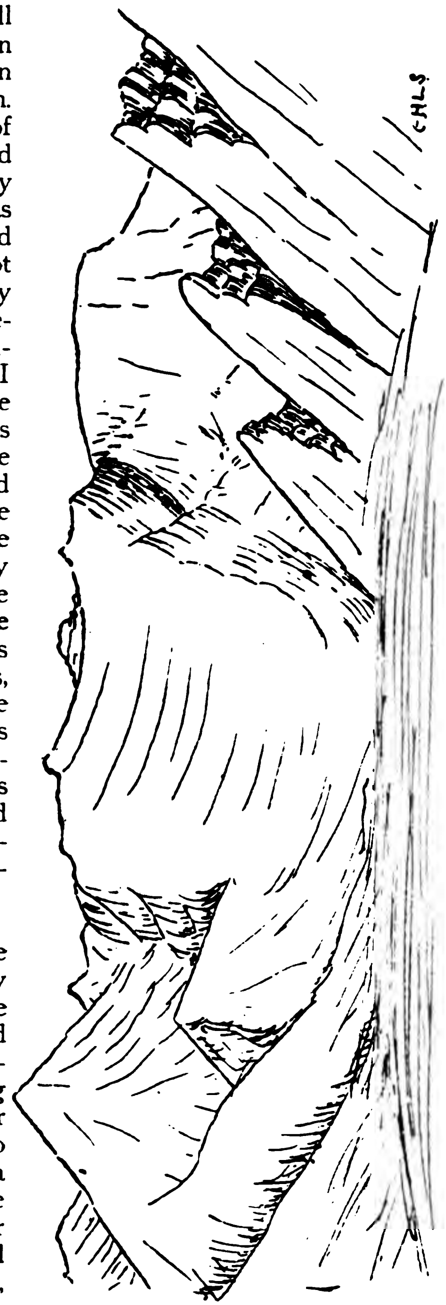

FIG. 11.—The axis of the Hex River syncline, pitching upwards at the Worcester end, as seen from Hex River Station.

Kloof, the plateau on the top of the Hex River Pass, and the Coo as remnants of a plain of denudation which we find further east, covered with river gravels at an average elevation of 3,500 and 4,000 feet. The top of Tafel Berg, in the Hex River valley, shown in the centre of the sketch (fig. 9), probably marks the original level of all these high tracks of Bokkeveld beds, and the plains as they now exist have been lowered some 500-800 feet by processes of denudation. Where the rivers have been active, the plains have been invaded, and low-lying valleys have been produced, like in the Warm Bokkeveld, lower Hex River valley, and the Kasey; but where the rivers have been only moderately graded, the plateau-form has been retained.

The Brand Vley valley is entirely covered with sand, and it is not till one nears Villiersdorp that the underlying Bokkeveld beds appear.

In among the Witteberg hills, to the north of Hottentot's Kloof, there is a valley composed of Bokkeveld beds, the higher zones of which alone are exposed. At Onverwacht I found small fronds of some plant like a liver-wort, with small raised rings, representing a kind of fructification. Mr. Seward, to whom they were submitted, failed to recognise their organic origin, so that nothing can be said further about them.

Taken as a whole, I was unable to find any zoning of the fossils, in spite of a considerable search for them and a careful noting of the horizons. What I found was that the animal remains occur spasmodically in pockets, and that, though most of them occur under the Fossiliferous sandstone, the same species may be distributed throughout the series. Even with the Fossiliferous sandstone, the fossils occur by no means universally, nor do they always represent the same animals; normally it might be called a Spirifer sandstone, but sometimes there are only lamellibranchs and crinoids in it, while again vast stretches are quite barren.

Lithologically there is some difference between the top and bottom of the series, but it is exceedingly difficult to fix on any characteristics; generally, perhaps, one can say that the bottom beds tend to a black, even-grained, mud deposit, whereas the higher are more micaceous and gritty. There is a good deal of pyrites in the form of films colouring the rock, as well as in small wriggling tubules, almond-shaped pockets, and larger nodules; some carbon is occasionally present; these, with a fair proportion of lime, which seems everywhere to impregnate the rocks, both shales and sandstones, rapidly cause disintegration on the surface, and render the original dark blue and black rock a reddish, yellowish, or even white, clay, or sandy shale.

When I was first surveying in the district, there was a great deal of prospecting going on for the purpose of finding oil. The rocks, being full of pyrites, often discolour the water that soaks out after the first rush of rain-water has passed, with iridiscent

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films of polysulphides, very similar to films due to oil. At Ceres itself there is a good deal of vley-ground, once a swampy marsh, but now drained and fit for cultivation; naturally a good deal of decomposed vegetable matter is contained in this soil, and oily substances are continually being given off which likewise give iridescent films. In addition to this, the prospectors found that the American geologists had attributed the formation of oil to the accumulation of organic material in rocks, such as the Marcellus shales, which are equivalent in age, and contain similar fossils, with our Bokkeveld beds. Nowhere in the district, however, did I see any large body of organic remains, nor did I see any porous rocks which could have served for reservoirs, supposing that the organic matter had been decomposed and converted into oil. Reservoirs for water there now exist in between the Table Mountain sandstone and the Bokkeveld beds, the different tensile strengths of the two rocks being sufficient to form cracks, or at any rate, potential cracks, which develop when the rocks are brougnt near the surface and released from great pressure. Such reservoirs, however, are of vastly younger date than the laying down of the Bokkeveld beds, so that I was reluctantly forced to come to the conclusion that there were no chances for successful boring for oil.

I was strongly of opinion, however, that the Table Mountain sandstone-Bokkeveld junction should be utilised for boring for water, as at one place especially, on the high ground above Uitkomst, I found a definite parting between the two series which was occupied by large quartz crystals, evidently deposited by water that had circulated in the cleft when the particular beds were deep in the ground; also I found that most of the natural springs come up on this junction.

A further description of the Bokkeveld beds as regards their distribution will be found in the last nine volumes of the Annual Report, and a detailed description of the beds will be found in the one for 1899. The fossils are described by Messrs. F. R. C. Reed and P. Lake in the Annals of the South African Museum, Vol. IV., "Descriptions of the Palæontological Material Collected by the Members of the Geological Survey."

THE WITTEBERG BEDS.

The Witteberg beds occur north of Ceres as an escarpment overlooking the Warm Bokkeveld. They consist essentially of hard yellow quartzites in beds of varying thickness, separated by micaceous shales, stained for the most part red. The original rock, both shale and sandstone, is blue, and the extreme result of weathering is a white rock, but on the surface the colours are usually those which I have just mentioned. At the base there is a series of micaceous slates and shales, with a bed of quartzite at the bottom; this latter contains on the Gydow Pass a number of worm tubes, and I tried at the time to fix this bed

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as the definite division of the Bokkeveld and Witteberg series. I found this worm-tube bed at other places, but it has been found impracticable to use it over the whole area of the Witteberg series, whether from want of exposures or absence of the particular bed, so that the separation of the two formations, which I at first thought was fairly easy to make out, has proved to be very difficult and uncertain.

I found in the series some plant stems and indistinct leaves, and there are also some curious bodies represented by casts, very much the same as the *Spirophyton cauda-galli* of the North American Devonian. The plant or sea-weed, for our specimens seem to necessitate the Spirophyton being organic, although Mr. Seward, to whom the specimens were submitted, denies this, grew from a root and then coiled round an axis in the form of a screw, the thallus being thin and wavy, and marked with sickle-shaped ridges. The margin of the thallus is marked by a continuous ridge. The thallus seems to have been very frail and thin, as in the ribbon, green sea-weeds, for the fronds overlap where they have been crinkled and subsequently squeezed by the pressure of the rock. The specimens from root to crown are some six inches high, and the breadth of the topmost whorl, usually about three inches, increases to six and eight inches in loose rock. The extraordinary thing about the Spirophyton is that such a frail organism has been able to stand upright during the sedimentation of coarse sand, for the plant often passes through two or three beds of sandstone, separated by shaley partings. Subsequently Mr. Rogers found a similar organism, only instead of the thallus being a continuous web winding round in a spiral, it is formed by a number of stout rods projecting from an axis, on the same principle as the other species. It is extremely improbable that two similar markings should occur in the same beds, and though so remarkably resembling each other in structure as to make them species of the same genus, that they should be inorganic, yet the ordinary form is classed as inorganic by Mr. Seward, and the rod form is labelled "roots."

The first specimens I obtained were very perfect casts from the Witteberg quartzites east of Brand Vley, but subsequently I found them frequently in the series.

In Ceres the Witteberg beds are very remarkable from the monoclines which traverse them. The rock is very well adapted to show off these small folds by its close bedding and intercalations of red shale between the yellow quartzites, as well as by the resistant nature of the quartzite which allows the faces of the krantzes to remain clear and sharp. Similar ones, no doubt, traverse the Table Mountain sandstone, but the massive banks of the series, unrelieved by differences of composition, and crumbling more readily on the surface, hide any but very large folds; occasionally, as in Kogman's Kloof, where exceptional circumstances obtain, the minor folds are also shown in the older rock system (Fig. 4).

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The monoclines run north-east, and continually bring down the Witteberg series, which is dipping north in places, east in others, with gradations between, in a series of step-faults, for a monocline is merely a fault without break, so that the surface outcrop of the Witteberg beds is far larger than it would be without them, and the apparent thickness of the series is thereby enormously increased. The true thickness of the Witteberg beds is not more than 2,000 feet.

FIG. 12.—The edge of the Gydow Mountains, overlooking the Warm Bokkeveld, with the highest point, on which there is the Trigonometrical beacon, Leeuwen Fontein, in the distance. Two monoclines are shown.

In Ceres there is the Gydow Berg, sometimes called the Waagenboom's Berg, made of the Witteberg series, and from this there is a long stretch, connecting with the mountains that bound the Karroo, the Bontebergen, on the east of Karroo Poort, and the Zwart Ruggens on the north. The outcrop of the beds makes almost a perfect right angle at Karroo Poort, just as the Table Mountain sandstone does by Ceres, that is to say, here the north-south folds meet the east-west folds. It is the interaction of these two simultaneous foldings which produce the "schaarung" or streaming of the structural lines, and the north-east monoclines are parallel to the direction of "schaarung." It is particularly to be noticed that in this case the folds or rock waves butt against each other, and produce divergence, whereas in other folds there may be two series that go on contemporaneously without any reference to each other, and thereby produce cross-folding.

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North of Karroo Poort the Witteberg series is puzzlingly like the Table Mountain sandstone; not only is the sandstone coarser than usual, but there are conglomerates with white quartz pebbles exactly as some parts of the older series. In addition, there is a definite shale-band near the top of the Witteberg beds, which is capped by a series of quartzites in the same proportions as hold good in the Table Mountain sandstone.

In the Witteberg sandstone this shale band is very important economically, for it is the seat of the major portion of the springs that issue from the hills. In the Table Mountain-Bokkeveld couple the seat of the water-parting is actually on the junction; but in the Witteberg-Dwyka couple, it appears in this neighbourhood at least to be behind the outcrop of the junction, some 300 feet below. The best example of this is at Hartnek's

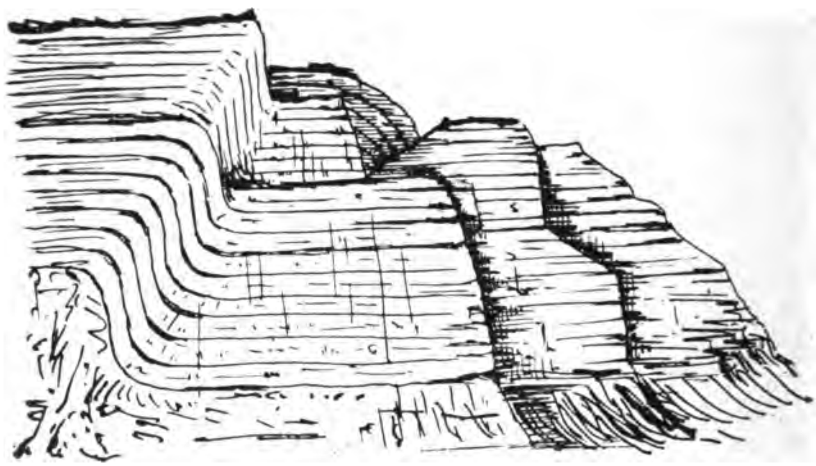

FIG. 13.—Monocline in the Witteberg hills, by Koekfontein, Gydow.

Kloof. The Witteberg dips steeply east, that is, Karroo-wards, rrom the Zwart Rug, and outside the main dip-slopes there is parallel series of great slabs of quartzite, separated from the former by the shale-band, exactly as occurs in the Table Mountain sandstone in the Schurftebergen, when seen from Prince Alfred's Hamlets. In the Kloof where the road comes down from the mountain, there is a sandy tract, with springs issuing through it. There is a good deal of black and brown sintery deposit from the spring water, with blood red or brilliant yellow patches in it. I was unable to carry a specimen of this material away, as it crumbled to fine dust in my bag, but I am assured that it is purely a deposit of an organic nature, formed by small water plants or possibly bacteria, and that there is no iron in the substance, as the brown sintery appearance would suggest, nor are the bright yellow patches sulphur, as the farmers confidently aver.

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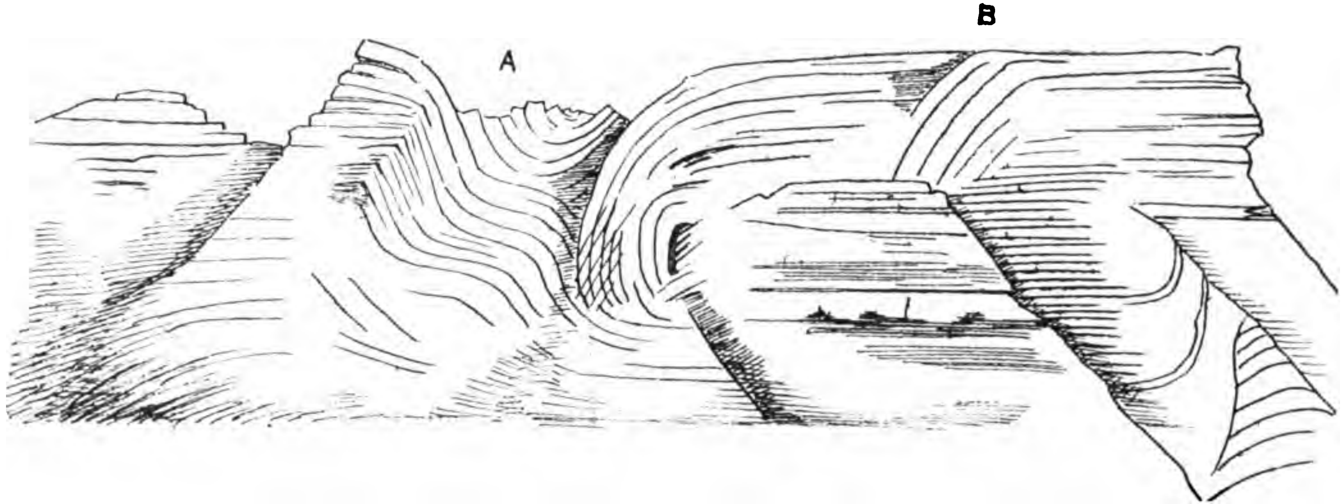

FIG. 14.—Two monoclinal folds, A and B, in Baviaan's Berg, looking from Het Drooge Zand. B goes through the kloof between Grass Berg and Het Drooge Zand's Berg, north of the Trigonometrical beacon. Below A there is a small farm house, with a spring issuing from the hillside. Water is very scarce in these hills.

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South of the Worcester-Swellendam fault there are hills of Witteberg beds, commencing near Brand Vley and passing south towards Villiersdorp, with a valley of Bokkeveld beds between them and the Table Mountain sandstone. They then turn round east along the Bosjesveld Berg, and come up to the fault near Robertson. Near Worcester they form prominent hills, and with their yellows and reds contrast with the grey of the Table Mountain sandstone hills. The presence of such beds near the Malmesbury series was a source of great perplexity, till I found Ecca beds lying against the Malmesbury beds, and I was thus able to explain these as strata that had been dropped by a great fault.

THE DWYKA SERIES.

The Ceres Dwyka beds are of historic interest, as north of the Gydow Berg I found the boulder, which was so typically ice-scratched that the glacial origin of the rock was adopted by the Geological Survey.

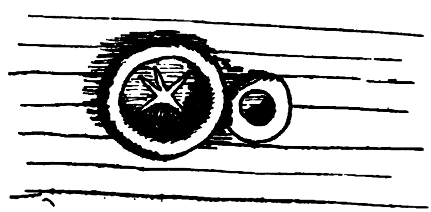

FIG. 15.—Spherical limestone concretions in Dwyka shales. The balls have broken across level with the surface, and the interior has been removed by atmospheric agencies quicker than the harder rind. The cracks produced by the drying of the concreton, now filled with white calcite, are shown.

North of the Gydow Berg the Dwyka beds are enclosed in a horse-shoe of Witteberg hills, closed on the north by an escarpment of Witteberg beds formed by a fault. The Dwyka conglomerate is fairly typical for southern localities, and I obtained most of the varieties of inclusions, such as quartzite, granite, limestone, jasper, and amygdaloid. The shales beneath the conglomerate are hidden by sand, and, in fact, it was not till considerably later that we began to realise the importance of these basement shales, and we did not in the beginning look for them. Passing northwards from Driefontein, the conglomerate is seen to be distinctly bedded; the rock dips at a slight angle northwards, and there are low escarpments with long dip-slopes, where the variation in the hardness of the rock has been brought out in weathering; on a small scale, however, bedding is not noticed, but on the other hand, shear-planes are com-

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mon, probably parallel to the bedding, or what would be the bedding, if there were sufficient variation in the matrix to show this structure. The shear-planes pass through the boulders, and the latter are often minutely and thoroughly broken up into parallel laminae without the matrix showing a corresponding number of planes of cleavage. The boulders thus cleaved are of all natures, amygdaloid and granite being equally affected with the quartzites and jaspers, and the original bedding of the pebbles has no effect on the direction of the cleavage planes.

As one reaches higher beds the boulders become sparser, and there are numbers of rounded calcareous concretions like cannon balls; when broken open, these show star-shaped cracks, filled with calcite (Fig. 15). Sometimes the concretions are simply matrix, cemented with calcareous matter; but again they may be rock with small gravelly inclusions so consolidated.

Higher up in the series one comes to definite shales, which split in long fingers, like the American "hone-stone" formation. The rock is soft shale, and the slabs are an inch or so broad, a half to a quarter of an inch deep, but may be many inches or even feet long. They are produced by close jointing in diagonal directions, one set of joint-planes being very much more numerous than the cross ones. The surface of the beds in these "hone-stones" show pittings which have been attributed to rain drops,* but which may be the effect of "balling" when the mud was soft, that is to say, the particles were aggregated by rolling before being pressed into a continuous mud, and this structure, after the rock had hardened, was preserved, and is now revealed by weathering. Prof. R. B. Young tells me that the muds forming in the lochs of Scotland are sometimes aggregated in this manner.

Outside Karroo Poort the Dwyka is much hidden by sand, and also by an immense amount of calcareous tufa; the latter points to a time when there was greater rainfall in the Karroo and the underground leakage was brought to the surface at the bend in the mountains that close it in. At present there is very little rain; the last that had fallen when I was there was three years previously, and the wells that are put down in the Dwyka conglomerate, though passing through creviced strata, which are filled in with lime deposited by percolating water, are not very successful.

At Beukes Fontein the extraordinary White Band comes in, but better exposures of it were found at a later stage of the survey. Here, however, there is a great development of gypsum, derived from the weathering of the pyritous shale, the sulphur uniting with the surface lime to form the calcium sulphate, or gypsum. The material lies about the hills in large lammelar slabs, like

* See illustration of a pencil of this substance with the pitted surface showing, in "An unrecognised agent in the Deformation of rocks," Trans. S.A. Phil. Soc., Vol. XIV., pt. 4, Plate 4, fig. 2.

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large sheets of mica, but it is only a surface deposit, and is not in sufficient quantity to repay exploiting. Some thin sandy beds are found here, full of indistinct plant stems, and the ironstone produced by the surface concentration of the iron derived from the decomposition of pyrites, or the pyritous material impregnating the shales, together with the chert, also occur here.

Between Robertson and Worcester, on the south side of the fault, there is a very fine exposure of Dwyka conglomerate, and it is a very extraordinary sight to see all the characters of a Dwyka conglomerate landscape, so typical of the country inside the circling hedge of mountains, reproduced on the south side of these.

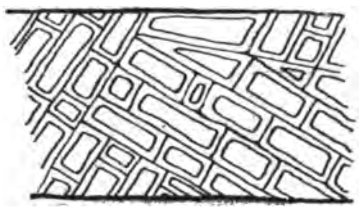

FIG. 16.—Figure showing weathering in upper Dwyka shales; the originally blue rock turns first red, and finally all the iron becomes concentrated along cracks, leaving the interspaces, white and pulverulent.

At Lange Vley the carbonaceous shales at the top of the Dwyka conglomerate have been prospected for coal, but the carbon content never exceeds 10%. The usual curiously coloured shales accompany this, and also the "snuff-box" bed, that is, a shale in which the iron of the binding substance has concentrated along cracks (Fig. 16).

ECCA BEDS.

The Ecca Beds did not come into the survey except south of the fault. It was at Worcester that I first found *Gangamopteris* in shales that I thought were Malmesbury beds, and had always been so mapped by previous geologists. North of the station the rock is unmistakably Malmesbury beds, with inclusions of marble and dykes of crushed granite, but in a quarry near the station there are red, thin-bedded sandstones, lying almost flat, with a slight inclination to the north-east. In among these there are layers of unctuous clay, coloured green with red mottlings, and in a thin bed of these, not more than an inch thick, I obtained many fragmentary kinds of *Gangamopteris* and *Glossopteris*, and small seed-like bodies which Mr. Seward has named *Cardiocarpus*. To the west of Worcester, along the railway line, there are a few kopjes projecting through the immense sheets of alluvium and river boulders. These are made

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up of green sandstones, in which a few fragmentary plant remains may be obtained by patient search, some of which can be identified as *Phyllotheca*.

Towards Robertson the Ecca beds are very strongly developed, and consist of a thick series of shales and sandstones of a prevailing green tint; the vegetation on them is very characteristic, and includes many of the typically African genus of *Cotyledon*, the most extraordinary of which is the boter-boom (butter-tree).

The Uitenhage Beds.

Above the railway cutting at Worcester Station, which gives one an exposure of Ecca beds, there is a red gravel, which belongs to the Cretaceous or Uitenhage series. It is formed of oval pebbles, about the average size of a tennis ball, and is evidently different from the recent gravels and boulder beds of the present river system. The matrix is a dark red clay.

On the east of the line, before it enters the poort in the Table Mountain sandstone hills by Ganze Kraal, there is an exposure of gravel, evidently very old, but of which the pebbles are made of slate. To the south-east of this, across the intervening low ground, there is a similar exposure of gravel near Nuy Siding, on the Cape Central Railway, but here the boulders are of white quartzite, like those of the gravels at Worcester Station, and I am of opinion that both the gravel composed of slate pebbles and that composed of quartzite pebbles are contemporaneous, and that both are Cretaceous in age; the difference in the nature of the boulders being due to the fact that each exposure originally derived its materials from near at hand, and at Ganze Kraal the nearest rock is Malmesbury clay slate, whereas at Worcester and Nuy, the rock is derived from the overhanging mountains of quartzite.

At the time of the survey very little was known about the Uitenhage series, and I could only chronicle at the time that these gravel deposits belonged to a time when the river system was altogether different from what it now is; but subsequently these outliers have been joined up with more extensive ones in Swellendam, Riversdale, and Knsyna, and fossils have been obtained from them which accurately fix their age as Cretaceous.

Recent Deposits.

The whole Breede River Valley from Tulbagh to Nuy is covered with extensive flats of sand and large rounded boulders of quartzite, derived from the Table Mountain sandstone; how much of this is material recently brought down from the mountains, how much true Enon conglomerate of the Uitenhage series, and how much re-made gravel of Uitenhage

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age, it is impossible to say. Certainly Enon conglomerate does occur in great masses of large white boulders in certain places, and the amount of fresh boulders that is brought down by the mountain torrents is entirely inadequate to explain the enormous quantity of white rounded boulders in the Breede River Valley, so that the weight of evidence seems to point to the rock immediately underlying the Breede River Valley, near Worcester, being part and parcel of the Uitenhage Series.

June 29th, 1905.

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A RAISED BEACH DEPOSIT NEAR KLEIN BRAK RIVER.

BY

A. W. ROGERS.

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A RAISED BEACH DEPOSIT NEAR KLEIN BRAK RIVER.

BY A. W. ROGERS.

Mr. George Robertson, of Klein Brak River, sent some shells to the South African Museum early in 1905. The shells came from a quarry on his farm, and they were obviously of more or less recent age, though belonging to species that are unfamiliar on the coast of Cape Colony. An opportunity occurred of visiting the spot in March, when Mr. Robertson kindly gave me every facility for examining the locality and obtaining a representative collection of the fossils preserved there.

The accompanying plan shows the position of the deposit and the geological formations in its neighbourhood, but it is certain that the old beach deposits occur elsewhere than in the one locality marked on the map.

A low ridge or terrace rising to a height of about 15 feet above the level of the Klein Brak River vley marks the position of the shelly beds, and small quarries have been opened in the ridge for the purpose of getting out limestone for building. The limestone is a loose textured, rather incoherent rock, but it hardens rapidly on exposure, and appears to stand the weather well. It contains a number of shells, which can easily be removed from the rock.

The following genera and species were recognised by Mr. E. A. Smith, of the British Museum, who kindly examined a collection sent to him :—

Gasteropods:

Turritella carinifera, Lamk.
    „ *knysnaensis*, Krauss.
Cerithium, sp. n.sp.?
Natica imperforata, Gray.
Cymatium cretaceum, Lamk.
    „ „ var. doliarium, Lamk.
Calliostoma, sp. n.sp.?
Nassa kraussiana, Dunker.
Priotrochus obscurus (Wood.).
Cassis achatina, Lamk.
Bulla ampulla, Linn.
Triton australis.

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Lamillibranchs:

Tapes corrugatus, Gmelin.
„ *deshayesii*, Sowerby.
Diplotodon, near *senegalensis*, Reeve.
Mactra glabrata, Linn.
Venus verrucosa, Linn.
Tellina rosea, Spengler.
Lucina liratula, Sowerby.
Lutraria capensis, Deshayes (narrow form).
Panopaea natalensis, Woodward.
Cryptodon globosus, Forskal.
Ostrea, sp.
„ sp.
Lima rotundata, Sowerby (large form).

All these species, with the exception of the *Cerithium* and *Calliostoma*, are known from the South African seas, though some of them, *e.g.*, *Panopaea natalensis* and *Triton australis*, do not appear to have been recorded from the coasts of Cape Colony. The local distribution of the South African marine mollusca is not well known at present, so that little can be said as to the changes indicated by the above list of shells from Klein Brak River.

Where the river has cut back into these deposits recently the limestone is seen to be underlain by a brown sandy clay, which contains shells, some of which are of the same species as those in the limestone, but they were too fragile from the effect of water to be collected during a short visit.

Both in the clay and in the limestone may specimens of lamellibranchs occur, with both valves intact, and amongst the heavy shells rolled and abraded specimens are not numerous in proportion to the unrolled.

In the limestone I found a piece of quartzite which appears to have been shaped by man. It has a form common to many rude implements of small size found on the surface in various parts of the Colony. Mr. Robertson told me he had found round stones flattened at one end, evidently by use as crushers or pounders, in the limestone.

Pebbles were not of frequent occurrence in the rock exposed at the time of my visit.

The limestone must have been formed at a time when the land stood at least 15 feet lower than now, and when the shore of Mossel Bay passed some two miles inland of its present position.

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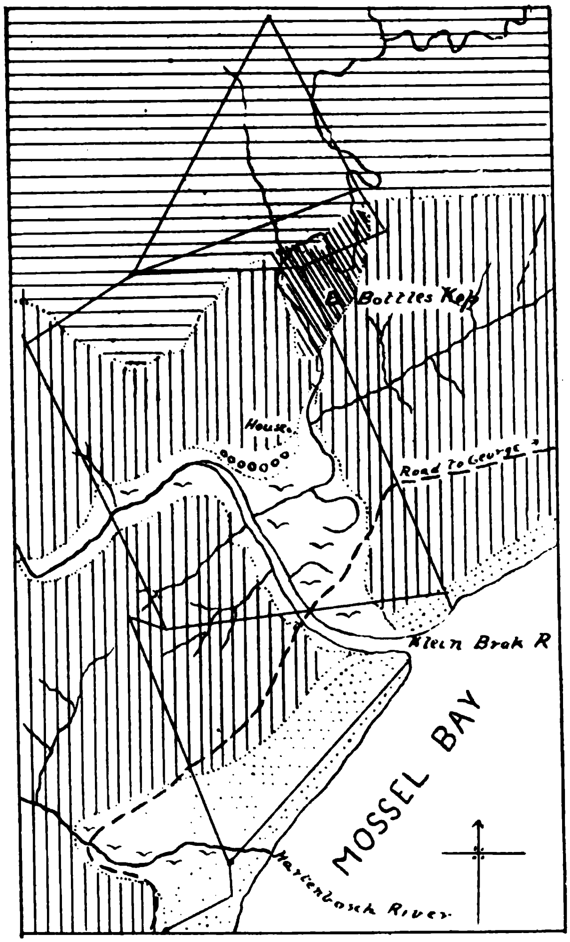
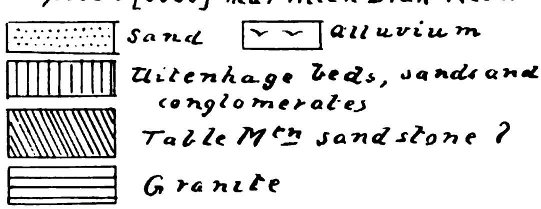


Map showing position of Raised Beach Deposits [0000] near Klein Brak River



Formation of a Siliceous Rock on the Surface.

Mr. Robertson drew my attention to a white crust on the surface of bare, dark, clayey ground sloping down to the vley on Klein Brak River. On first looking at it I took it to be a calcareous tufa, such as is found on the surface in parts of the Colony where calcareous rocks lie under the soil, but on breaking it up the interior was found to be dark coloured and transparent at the edges, very much like flint. The thickest layer was about three-quarters of an inch thick. The white colour seems to be due to the loose state of the silica. Under the microscope thin chips of the dark rock are perfectly transparent, and behave between crossed Nicols in the same way as chalcedony.

The specific gravity of the material is 2·56, lower than that of chalcedony, which is given as 2·62 in Mier's "Mineralogy."

Mr. Robertson told me that this crust forms on the surface after wet weather .n bare places when these places are undisturbed.

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